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REGIONAL AIR POLLUTION STUDY (RAPS) EMISSION INVENTORY HANDBOOK. VOLUME 2

Rockwell International

Prepared for:

Environmental Sciences Research Laboratory

February 1976

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RAPS EMISSION INVENTORY HANDBOOK

Volume 2

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16. ABSTRACT

The Regional Air Pollution Study (RAPS), which encompasses the St. Louis Air Quality Control Region, is the largest and most comprehensive attempt to date to obtain a quantitative understanding of urban air pollution. Its aim is to describe the complex relationships between emissions to the atmosphere, atmospheric dispersions and transformation processes, and ambient concentrations of pollutants. In addition, numerous corollary studies are planned under the RAPS "umbrella."

An accurate, detailed and comprehensive inventory of emission to the atmosphere constitutes a basic input to this understanding. The RAPS emission inventory was planned to provide far more detailed information than has been available anywhere in the past; its aim is to obtain hourly data for key pollutants based insofar as possible, on measured values. Thus, emission data should be available for a base period of a year, commensurate in detail and accuracy with data on ambient concentrations and micrometeorological information gathered by the Regional Air Monitoring Stations.

The ultimate value of the RAPS Study will, it is hoped, not be confined to the St. Louis area, but rather will provide a model for future studies of this type in other areas. For this reason the National Air Data Branch provided complete documentation of all efforts connected with the assembly of the regional emission inventory so that the techniques and methodology developed for this project will be applicable to future studies.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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SOURCE CLASSIFICATION

V

Classification of Sources

The classification of sources for the Regional Air Pollution Study is presented in this section of the handbook (1).

1. Regional Air Pollution Study (RAPS) Preliminary Emission Inventory, Stanford Research Institute, PB 232-223/AS, January 1974

1. Classification Scheme

A general classification scheme for emission sources is presented in Table 10. It is broad enough to encompass all emissions of pollutants from all sources. The source categories (stationary and mobile) and subcategories (area, line, and point) are convenient from the standpoint of dispersion modeling as well as from inventory organization. The division of source processes into combustion and

Table 10

CLASSIFICATION OF SOURCES FOR EMISSION INVENTORY

Source Category	Stationary Sources				Mobile Sources	
Source Subcategory	Area Sources		Point Sources		Area and Line Sources	
Source Process	Combustion	Noncombustion	Combustion	Noncombustion	Combustion	Noncombustion
Source units	Commercial Institutional Residential Small industrial Fuel Use Space heaters Water heaters Boilers Waste disposal--incinerators	Commercial Small industrial--Venting of organic vapors (dry cleaning, painting, gasoline storage and handling, food preparation)	Utilities Power plants Municipal--incinerators Industrial Boiler and power plants Indirect-fired air and process heaters Stationary internal combustion engines Stationary gas turbine engines Incinerators	Industrial Direct-fired process units All other industrial processes, material storage and handling	Surface vehicles Passenger cars Trucks and buses Commercial vehicles Railroads Vessels Off-highway vehicles and equipment Aircraft Piston engines Gas turbines	Surface vehicles and aircraft Venting of fuel vapors Wear of tires and brakes
Pollutants	Gases and vapors SO_x NO_x CO Hydrocarbons and derivatives HCl HF Odors Particulates Fly ash and its specific chemical components Smoke	Gases and vapors Organic vapors (solvents, gasoline) Odors Particulates Organic aerosols Smoke	Gases and vapors SO_x NO_x CO Hydrocarbons and derivatives HCl HF Odors Particulates Fly ash and its specific chemical components Smoke	All pollutants	Gases and vapors SO_x NO_x CO Hydrocarbons and derivatives Odors Particulates Smoke Lead Oil aerosols Derivatives of fuel additives	Hydrocarbon vapors Particulates Organic Inorganic

noncombustion processes is a convenient one that is not subject to serious ambiguities. Combustion processes are here defined as those in which the release of pollutants comes solely from the burning of fuels or wastes. They include all processes in which there is indirect transfer of the heat produced (e.g., water heaters and boilers, indirect-fired air heaters) as well as incinerators, internal combustion engines, and gas turbines.

Noncombustion processes comprise all other pollutant sources not falling under the specific definition of combustion processes given above. In many of them, combustion of fuels actually does take place, but the products of combustion come into contact with other process materials that may give rise to pollutant emissions; examples are direct-fired driers, calcining kilns, cement kilns, and paint-baking ovens. In other cases, the process emitting pollutants may have no direct contact at all with products of fuel combustion; many processes for manufacturing organic chemicals are in this class. Heating of such processes is by indirect transfer from combustion processes that they themselves constitute separate combustion sources. Still other processes involve only venting or ventilation, with consequent release of pollutants to the atmosphere; examples include dust emissions from flour mills and solvent emissions from paint spray booths.

2. Stationary Sources

a. Point Sources

Combustion Sources--The major point combustion sources are utilities and industrial plants. The largest industrial sources are commonly the power and steam plants. However, there are other types of indirect-fired process heaters (e.g., pipe stills in petroleum refineries) that are used for heating various kinds of process fluids and heat transfer media other than water.

Utility power plants handle a fluctuating generating load that usually follows a fairly well-defined cycle. The typical load passes through a minimum in the early morning hours. The absolute levels and the hours at which the minimum and maximum loads are reached are functions of the season of the year. Summer and winter loads reflect the effects of air conditioning and space heating loads. The patterns for different power plants may vary widely, however, depending on whether a plant is handling a base load or is being used for peaking.

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Industrial power and steam plants will usually display load patterns substantially different from those of the public utility plants serving the general area. Where the manufacturing plants are operated on a 24-hour basis, both the electrical power and the steam required for process use should in general represent fairly steady loads. On the other hand, the power and steam plants will be essentially if not completely shut down when the manufacturing plant is out of operation. The power and steam required for heating and air conditioning the plant will superimpose a fluctuating load on that resulting from process requirements.

The nature of the load cycle in an industrial power plant will also be affected if the plant is tied into the public utility power grid. In such cases the plant will usually send power into the public system when power demand is low in the manufacturing plant and draw power from the public system when demand is high.

Depending on the type of manufacturing, electrical loads may exhibit cyclic behavior, sometimes over relatively short intervals (e.g., electrical power loads in a steel rolling mill). Batch chemical processes may have a cyclic steam demand.

To obtain a significant emission inventory from such sources, particularly an inventory from which it is possible to simulate one-hour emissions, it is necessary to acquire detailed knowledge of the operating cycle of each installation as well as of the characteristics of the installation itself, the fuel or fuels used, and so on. A sampling program to acquire information for derivation of representative emission factors will have to be carried on.

Although emissions from such sources are commonly estimated by emission modeling techniques (as described in Section VII) using information on load and operating patterns discussed above, we recommend that, wherever possible, emission data from the point sources responsible for the major proportion of emissions be acquired by direct methods using information on actual emissions, loads or fuel consumption. Details of this approach are given below.

Incinerators constitute another point combustion source. The sulfur contents of common wastes are low, so that incinerators are only rarely significant sources of sulfur dioxide. The variability of the composition of wastes will, however, make it much more difficult to correlate the measured emissions with operating variables than with fuel-burning combustion sources.

The design of most existing incinerators has not been favorable to efficient combustion, so that emissions of carbon monoxide and hydrocarbons tend to be much higher than in fuel-burning operations. This problem is frequently aggravated by improper operating conditions. The formation of nitrogen oxides can vary widely depending on incinerator operating temperatures as they are affected by the amount of excess air used in combustion.

Since the variations between different incinerators may be extreme, emissions are relatively unpredictable. Hence, any large units (municipal incinerators and possibly some industrial incinerators) should be tested individually, i.e., on the basis of operating data, such as daily tonnage of throughput. Smaller industrial and commercial incinerators may be treated by modeling with only representative units being sampled, since their emissions will be small enough to be estimated with adequate precision from such data.

Noncombustion Sources--Noncombustion point sources of pollutants are practically exclusively industrial in nature. They comprise such a diverse collection of manufacturing operations that no generalizations can be offered concerning either their emissions of pollutants or the factors affecting them. Most noncombustion point sources will emit one or more of the pollutants of concern to the dispersion model studies, as is shown in the following discussion under each pollutant.

The principal point noncombustion sources of SO_2 are found in petroleum refineries, nonferrous smelters, sulfuric acid plants, and--possibly--integrated steel mills.

In petroleum refineries, the process sources are the Claus sulfur plants, the regenerators of catalytic cracking units, and flares burning waste sour refinery gases. Refinery process heaters or boiler furnaces burning sulfur-containing fuels (including sour refinery gases) fall in the category of point combustion sources discussed above. The flare represents only a combustion source, but it is one of such specialized nature that it is best classified with the process sources. Because of its irregular operation, the flare presents special problems of emission estimation, which must be worked out in reference to process measurements available and with consideration of the actual level of SO_2 emmissions for which the source is responsible. Claus sulfur plants are likely to be fitted with continuous monitors for measurement of SO_2 in the tail gases. In the event that they are not, manual measurements of SO_2 emissions must be made and correlated with an available measured process variable, such as sulfur production rate. Measurements of NO_x emission, also required, will probably have to be made manually. The regenerator of a catalytic cracking unit is not only a source of SO_2 but (at least potentially) a major point stationary source of CO. The actual emission of CO depends on whether the regenerator is fitted with a CO boiler and on the combustion efficiency of the CO boiler. The SO_2 emission is related primarily to the sulfur content of the petroleum feedstock being processed in the catalytic cracking unit. Measurements must be made of the SO_2, CO, and NO_x concentrations in the waste gases and of the waste gas flow. The quantities can probably be correlated with the throughput rate of catalyst being regenerated. The sulfur content of the cracker feedstock will be an added parameter of the SO_2 emission.

In secondary nonferrous smelters, the principal source of SO_2 emission is likely to be the fuel used, and the measurements and correlations of the emissions will be similar to those employed in combustion sources. However, primary smelters operating on sulfide ores are potentially major point sources of SO_2 emissions. Apparently, there are no primary nonferrous smelters operating in the Saint Louis area completely without SO_2 recovery (by manufacture of sulfuric acid). However, the tail gases from the sulfuric acid plants operating on smelter gases can themselves be major sources of SO_2 emission, as noted below.

Contact sulfuric acid plants, whether sulfur-burning units or by-product acid plants, are at least potentially major sources of SO_2 emissions. In the future, at least, they will probably be equipped with continuous monitoring devices for measurement of the SO_2 concentration in the tail gases partly for process control. Whether manual or automated, determinations will have to be made of SO_2 and NO_x concentrations and waste gas flow rates. The results must then be correlated with operating variables, such as the acid production rate.

Integrated steel mills have a common major source of actual or potential SO_2 emissions--the production of coke oven gas--which has a substantial sulfur content. If the coke oven gas is not desulfurized before use, the sulfur will be emitted as SO_2 from the various combustion sources (e.g., power houses, underfiring of coke ovens) or process sources (e.g., open hearth furnaces, soaking pits) where the gas is used as fuel, and it will be accounted for in the emissions inventories of those sources. If the coke oven gas is desulfurized before burning, a Claus plant or a contact sulfuric acid plant will be used to convert the recovered hydrogen sulfide to elemental sulfur or sulfuric acid. Whichever may be used, the tail gas will constitute a SO_2 emission source that must be investigated as discussed above.

In addition to the principal noncombustion sources of SO_2, there are a variety of direct-fired processes in which SO_2 emissions can arise from the fuel burned or, possibly also in some instances, from the material being processed. Important examples are drying and calcining kilns and cement kilns. These sources are probably more important for their emissions of other pollutants, such as particulates and NO_x, than for their SO_2 emissions. Cement kilns, because of their high operating temperatures, are probably relatively important sources of NO_x, but there are few reliable data on their emissions of SO_2. Measurements of both NO_x and SO_2 emissions and their correlation with cement kiln operating conditions are particularly important because cement kilns are relatively large consumers of fuel.

Major point noncombustion sources of CO, actual or potential, are relatively rare. Catalytic cracking unit regenerators have been listed above because they are also sources of SO_2. The blast furnaces in steel mills are probably the only other important examples. Safety considerations alone normally dictate that blast furnace gas not used as fuel be burned in a flare before discharge to the atmosphere. Venting of some unburned gas from relief valves at the tops of blast furnaces does take place intermittently as the result of "slips" in the furnace that produce surges in gas pressure. However, the fraction of the total gas generated that is lost in this manner is relatively small under modern operating practices. The total gas generated is computed from the volume of air supplied to the furnace, and the amounts used as fuel or flared are commonly metered. The amount lost by venting during slips is obtained by difference. The average daily loss is thus obtainable with reasonable precision, although the actual releases are commonly of short duration--a matter of minutes. Establishing the actual hourly emission rates of CO from this source is probably impractical, but it is also unlikely that the amounts are large enough to seriously affect CO dispersion studies except possibly in the locality of a steel plant.

Apart from the types of point noncombustion sources of NO_x already mentioned, nitric acid plants constitute the major process source of NO_x. The NO_x concentrations in the tail gases are likely to be monitored continuously as a process control measure. If they are not, manual sampling and flow measurements must be used to develop a correlation between the NO_x emission and the measured production rate of nitric acid (or some other convenient operating variable).

The NEDS inventory data indicate that petroleum refineries constitute the major point process emission sources of hydrocarbon gases and vapors. A substantial amount of the total emissions from refineries is known to often result from a multiplicity of small leaks and vents, so that the source location is rather diffuse. Control of such emissions has been made difficult by the small sizes of many of the individual leaks. However, vaporization losses from storage tanks has been a large and specific source of hydrocarbon emissions. Losses from evaporation occur not only in refineries, but also in subsequent handling and storage of gasoline and other hydrocarbons liquids; estimates of such emissions should be made wherever possible.

Other point sources of emissions of hydrocarbons and hydrocarbon derivatives will include large surface coating operations, such as the spray painting of automobiles at assembly plants. Data will have to be developed on the actual consumption of coatings and solvent in these operations and on the rate of consumption. Even the operators may not currently have reliable data on anything but the gross long-term consumption.

Chemical analyses should be made to classify the hydrocarbons and hydrocarbon derivatives emitted according the major groups (paraffins, olefins, diolefins, aromatics, alcohols, ketones, and aldehydes). Where possible, the actual material vaporized, not the liquid stocks, should be sampled.

To summarize, Table 11 shows the major noncombustion sources and the basis of the principal pollutants emitted.

b. Area Sources

Combustion Sources--The stationary area sources are composed of:

- Residences.
- Commercial establishments.
- Institutional establishments (e.g., schools, hospitals, public buildings).
- Some small industrial (manufacturing) establishments.

Most of the pollutants arise from the combustion of fuels used for cooking, space and water heating, and steam generation. Some may come from combustion of wastes in small incinerators. Industrial establishments in this category are composed mostly of small manufacturing operations that employ fuels primarily for space heating or that burn small quantities of waste.

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Table 11

MAJOR NONCOMBUSTION SOURCES OF POLLUTANTS

Pollutants	Sources
SO_2, SO_3	Contact sulfuric acid plants Claus sulfur plants Coke oven gas production Copper, lead, and zinc smelters Sulfonation of organic compounds
NO_x	Nitric acid plants Nitration of organic compounds
Particulate matter	BOF steel furnaces Secondary lead smelters Grey iron foundries Flour mills Cement plants Coke quenchers
Hydrocarbons and derivatives	Organic chemicals manufacture Paint and varnish manufacture Coating of fabrics with rubber or plastics Venting of storage tanks for petroleum products and organic chemicals

The rate of fuel consumption by the area combustion sources exhibits pronounced diurnal and seasonal variations as well as variations related to ambient temperatures. Fuel consumption peaks appear over periods of one to three hours. The consumption patterns of residences differ from those of commercial, institutional, and small industrial operations, which may operate at night and over weekends as well as during the day. The different types of sources may also use different kinds of fuel. Individual residences and small apartments tend to use natural gas, whereas large apartment houses and commercial, institutional, and industrial operations are relatively more likely to use oil or coal.

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The amounts and nature of the emissions from fuel combustion are related not only to the type of fuel burned but also to the type and the size of the combustion equipment. If waste incineration is used, the practices employed in incineration may vary widely.

The only feasible way to develop an emission inventory for the area combustion sources is to apply emission factors characteristic of the combustion equipment to the quantities of fuels consumed. Unfortunately, there will seldom be data that will give directly the quantities of various fuels consumed by particular types of equipment and by specific types of users. The flow of natural gas to various sections of a city may be measured at metering stations. However, the measurements will indicate only the temporal pattern of the total flow to all users. Data on sales of oil and coal indicate only the average rates of consumption over relatively extended periods of time.

For significant area sources, it will be necessary to determine, by survey and experiment, the amounts and the patterns of fuel usage by typical components of area sources. For instance, the consumption of fuel by a typical apartment for cooking, water heating, and space heating could be measured and fitted to a model incorporating diurnal and seasonal influences and the effects of ambient temperature. Pollutant emission factors should be determined experimentally for the combustion devices unless they are already available. Similar determinations should be made for other representative source units: individual homes, offices or office buildings, retail stores, and such.

Noncombustion Sources--The most important noncombustion area sources are those that emit organic vapors and may make appreciable contributions to the total emission of hydrocarbons. Prime examples include vapors from (1) gasoline storage and handling by distributors and service stations, (2) dry cleaners, (3) painting, (4) degreasing, and (5) application of asphalt to roofing and pavement.

The total quantity of vapors released can be estimated fairly readily by applying appropriate emission factors to the quantity of gasoline handled, the amount of cleaning fluids consumed, the amount of paint applied, and so on. However, attainment of adequate spatial and temporal resolution will require a fairly extensive survey of the sources and a detailed study of operations at a representative sample of establishments or activities of each type.

The emissions of gasoline vapors from automobile service stations will vary with the day of the week and the hour of the day, as the volume of business fluctuates. The emissions of cleaning fluid vapors from dry-cleaning establishments are probably relatively constant during actual working hours. Solvent vapor emissions from the painting of products in small manufacturing establishments and from solvent degreasing operations should have a similar temporal pattern. However, the emissions of solvent vapors from the painting of buildings (interior and exterior) are irregular with respect to quantity, time, and the location of the activity. Nonmethane hydrocarbons are also emitted in significant quantities in summer daylight hours. (See Section VII.) Specific estimates for the Saint Louis area are needed before that contribution can be properly evaluated.

Again, for the major contributing sources of this type we recommend the direct approach to determining emissions data described later.

3. Mobile Sources

The determination of emissions from mobile sources presents special difficulties. The problem has received considerable attention in connection with air quality modeling specifically related to the nature and variability of traffic sources. In studies of this type (as described in detail in Section VII) a considerable degree of sophistication has been achieved in some cases. In these however, it has been convenient and appropriate to consider the relationships between the behavior of the sources and the ultimate air quality conditions in models which integrate and combine the various parameters involved in ways specific to the purpose for which the model is designed. In many respects, current modeling capability in this area is inadequate, and its improvement will be an important aspect of the RAPS program. The basic RAPS Emission Inventory may properly be expected to provide basic data for the use of such modeling development, and thus data on traffic flow and traffic links will be part of the data collected and stored. For the primary needs of the principle users of RAPS, however, the inventory must provide data on the emissions of the key pollutants from mobile sources, which contribute to overall input of emission data to air quality modeling or transformation process studies. Accordingly, we recommend that, until more refined inputs are available as a result of progress in mobile source emissions modeling studies, the basic traffic data be used with simple models based upon average speed to develop the initial information on emissions of the key pollutants.

POINT SOURCES

Point Source

The methodologies involved in developing an hourly emission inventory for point sources are described in this section of the Handbook. The first section on preliminary information was an initial survey and evaluation of existing data (1). The next four parts, Point Source Methodology (2), Hydrocarbon Inventory Methodology (3), Heat Emission Methodology (4) and Emission Factory Development (5) relate directly to the hourly emission inventory for RAPS.

1. Regional Air Pollution Study: (RAPS) Preliminary Emission Inventory, Stanford Research Institute, PB 232-223/AS, January 1974
2. Point Source Methodology, Rockwell International, Science Center, EPA 450/3-74-054, October 1974
3. Methodology for Inventorying Hydrocarbons, GCA/Technology Division, November, 1974, Contract No. 68-02-1006, Task 7
4. Heat Emission Methodology, (Under development) Rockwell International, Air Monitoring Center
5. Emission Factor Development: Developed for this handbook by the National Air Data Branch, April 1975

SURVEY AND EVALUATION OF EXISTING EMISSION INVENTORY DATA

A. Introduction

Air pollution studies have been conducted in the Saint Louis area for many years, and several emission inventories have been developed. To avoid any unnecessary duplication of effort, it was important to review the existing emission inventories, to compare their content with the information needed for RAPS, and, if they appeared to contain useful information, to transfer this information to the RAPS inventory.

The City of Saint Louis has been involved in air pollution control since its first antismoke ordinance was passed in 1893. Smoke and fumes were, of course, the first targets of pollution control efforts; even so, 50 or 60 years passed before effective pollution control measures were applied to the largest pollution sources of the Saint Louis area, the power plants and the steel mills. In 1964, an "Interstate Air Pollution Study, Saint Louis-East Saint Louis Metropolitan Areas" was undertaken by the U.S. Public Health Service. Questionnaires were sent out to determine fuel use and combustible waste disposal practices in the area as well as manufacturing activities. A revised emission inventory, still based on 1963 data, was published in December 1966 as Phase II of the interstate study.

After the Metropolitan Saint Louis Interstate Air Quality Control Region had been established, the first comprehensive inventory was taken in 1968, to serve as a basis for the Implementation Planning Program (IPP). This inventory included the jurisdictions of Jefferson, Saint Charles, and Saint Louis Counties and Saint Louis City in Missouri; and Madison, Monroe, and Saint Clair Counties in Illinois. Franklin County was added in 1969. Four additional Illinois counties, Bond, Clinton, Randolph, and Washington, were added to the air quality control region in 1971. Only sulfur dioxide (SO_2) and particulates were included in the initial IPP inventory. The more recent inventories contain estimates of carbon monoxide (CO), hydrocarbons, and oxides of nitrogen (NO_x) as well. The following inventories are described in some detail in Section II:

- IPP Emission Inventory-1968
- IBM Emission Inventory-1970
- DAQED Emission Inventory-1971

- NATO Emission Inventory-1971
- NEDS Emission Inventory-1973

In addition, the following traffic and transportation inventories are discussed:

- Streets and highways
- Railways and vessels

The emission inventories in current use by the Missouri and Illinois regulatory agencies were recently (Summer 1973) acquired and transferred to the NEDS files under another contract; therefore, they are not considered separately.

Contact was also established with research groups, such as the Metromex consortium, active in the Saint Louis area. However, these groups do not have any emission inventory data. Nor were any data available from industrial sources, such as the Waste Control Council.

The data available from the various air pollution control organizations deal with pollution arising from industrial, commercial, residential and traffic activities. There appear to be no direct emission data on such transient sources as agricultural spraying or fugitive dust.

B. Existing Emission Inventories for the Metropolitan Saint Louis Interstate Air Quality Control Region[*]

1. IPP Inventory-1968

The Implementation Planning Program (IPP) emission inventory covering sulfur dioxide and particulate matter in the six counties and the City of Saint Louis originally making up the Air Quality Control Region was assembled by the EPA Region VII office in 1968. This inventory was used by Argonne National Laboratory as a basis for diffusion modeling in the development of the IPP for Illinois and Missouri.

The 1968 inventory lists yearly emissions of SO_2 and particulates from 116 major spot sources and 316 area sources, on the basis of questionnaires and letters of intent filled out by local agencies. Typical printout pages are shown in Figures A-1 and A-2 in Appendix A.

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[*] The pioneering interstate study by U.S. P.H.S. is mentioned above on page 107.

2. IBM Inventory-1970

In 1970 the International Business Machine Company (IBM) compiled an emission inventory for the Office of Air Programs. This inventory included only three Missouri counties (Jefferson, Saint Charles, and Saint Louis) and Saint Louis City; therefore, it is not directly comparable with other inventories in the area.

Though it covers a smaller area, the IBM inventory is considerably more detailed than the IPP inventory. It contains data on 105 point sources, giving their location; stack parameters; fuel consumption data; and calculated SO_2, particulate, CO, hydrocarbon, and NO_x emissions in tons per year (Figure A-3, Appendix A). From these data, emission inventories were calculated for each of the political jurisdictions.

In the IBM inventory, area sources were treated by counties. Each county was divided into source areas, varying in size from 4 to 700 square kilometers. For each area, emissions of particulates, SO_2, CO, hydrocarbons, and oxides of nitrogen were calculated for domestic, commercial, and industrial sources, as well as for incinerators and motor vehicles. A summary of the data is shown in Figure A-4, Appendix A.

3. DAQED Emission Inventory-1971

The former Division of Air Quality and Emission Data (DAQED) acquired an emission inventory for the Saint Louis area by using the rapid survey technique described by Ozolins and Smith.[13] This technique is based on information available in most urban areas; it does not entail extensive surveys or sampling procedures. The results are, however, considerably more accurate than those derived by gross approximations based on published production or consumption data.

The inventory included SO_2, particulate matter, CO, hydrocarbons, and oxides of nitrogen. The data are given in metric units. Summary information on population, area, some background information, and air quality data, is shown in Tables 15 and 16.

4. NATO Emission Inventory-1971

The North Atlantic Treaty Organization (NATO) emission inventory for the Metropolitan Saint Louis Interstate Air Quality Region was prepared in 1969 to serve as a comparison and model for the development of emission inventories in Frankfurt, Germany, and Ankara, Turkey. The so-called NATO Emission Inventory covered the following pollutants:

Table 15

SAMPLE OF DAQED Inventory
SO_x Emission Summary

REGION ST. LOUIS, MISSOURI-ILLINOIS
COUNTIES Jefferson, St. Charles, St. Louis (Mo.); Madison, St. Clair (Ill.)
POPULATION 1 678 251 AREA 9 239 sq. km.

EMISSIONS	RAPID SURVEY SO_x tonne/yr.	PARTICULATE
FUEL COMBUSTION		
Power Plant	334 000	46 000
Residential	45 000	20 000
Ind. & Comm.	113 000	46 000
PROCESS	107 000	44 000
REFUSE DISPOSAL	575	4 500
TRANSPORTATION	4 600	8 000
TOTAL	604 000	169 000
Emissions per capita	0.360	0.101
% of total emissions from the 5/3 largest sources.	75%	28%

a.	Meramec, P.P.	Monsanto
b.	Portage de Sioux, P.P.	West Lake
c.	St. Joseph Lead	Wood River, P.P.
d.	Venice, P.P.	
e.	Wood River, P.P.	
f.		
g.		
h.		
i.		
j.		

BACKGROUND INFORMATION: St. Louis is located at the confluence of the Mississippi and Missouri Rivers and near the geographical center of the U.S. The terrain is flat. Winters are brisk but seldom severe and summers are hot and humid. Inversion potential is low.

EMISSIONS: Most of the sulfur oxide emissions are discharged during combustion at power plants and industrial sources. More than 7.2 million tonnes of 3% sulfur coal is consumed annually. The largest industrial process sources are smelting, sulfuric acid manufacturing and refineries. Particulates are emitted primarily from the combustion of coal, with an average ash content of 9%. Other large sources of particulates are the grain industry, steel mills, cement and ammonium nitrate plants and rock processing.

APPRAISAL OF AIR QUALITY: Emission rates for both SO_x and particulates are quite high, and, as a consequence, the quality of the atmosphere has undergone considerable degradation. This supposition is supported by considerable ambient data on both pollutants. These adverse pollutant levels are to be expected in an area with such a concentration and variety of widely distributed industries plus numerous large power plants.

REGION ST. LOUIS, MISSOURI-ILLINOIS

Table 16

SAMPLE OF DAQED INVENTORY
CURRENT AND TREND DATA, AMBIENT CONCENTRATIONS

A. TREND DATA

Station*		SO_2 ug/m^3 64	65	66	67	68	69	TREND	SUSPENDED PARTICULATE ug/m^3 64	65	66	67	68	69	TREND
U E. St. Louis 1 NASN	Ann. Av.									189	187**	148	114	112	-
**City	24-hr. Max.									401	323	249	229	209	-
U St. Louis 1 NASN	Ann. Av.	87			87	91	73		138	143	135	111	186		0
	24-hr. Max.	292			294	193	266		278	260	255	184	480		-
U St. Louis 2 CAMP	Ann. Av.	160	130	100	80	80		-			163	121	132	124	-
(SO_2 continuous)	24-hr. Max.	680	500	470	550	420		0			394	296	378	356	-
U St. Louis 1 City	Ann. Av.									319	154	179			
	24-hr. Max									514	649	524			

AVERAGES ARE ARITHMETIC

AVERAGES ARE GEOMETRIC

B. CURRENT DATA

Station*	SO_2 ug/m^3 Ann. Av.	24-hr. Max.	1968 1-hr. Max	SUSPENDED PARTICULATE ug/m^3 1969 Ann. Av.	24-hr. Max.
U E. St. Louis 1 NASN				112	209
U St. Louis 1 NASN	73	266 (1969)			
U St. Louis 2 CAMP	80	420	1780	124	356
U St. Louis 2 City				151	438
U St. Louis 3 City				89	207

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[*] Station Location Codes: U= urban; S= suburban; R= rural.
Trend Column Codes: += upward trend; 0= no trend; -= downward trend.

REGION ST. LOUIS, MISSOURI-ILLINOIS

- Sulfur dioxide
- Particulates
- Carbon monoxide
- Hydrocarbons
- Oxides of nitrogen

Essentially, this inventory was an updating from the IPP and DAQED emission inventories of all area and major point source emissions. In June, 1971, the NATO inventory was further updated by using new emission factors.

The NATO inventory is the most versatile of the inventories discussed so far. The data are grouped in the following 23 sections:

(1) Summary if Air Pollutant Emissions, Study Area.

(2) Summary of Air Pollutant Emissions, Saint Louis City, Missouri.

(3) Summary of Air Pollutant Emissions, Saint Louis County, Missouri.

(4) Summary of Air Pollutant Emissions, Jefferson County, Missouri.

(5) Summary of Air Pollutant Emissions, Saint Charles County, Missouri.

(6) Summary of Air Pollutant Emissions, Franklin County, Missouri.

(7) Summary of Air Pollutant Emissions, Madison County, Illinois.

(8) Summary of Air Pollutant Emissions, Monroe County, Illinois.

(9) Summary of Air Pollutant Emissions, Saint Clair County, Illinois.

(10) Summary of Air Pollutants from Point Sources.

(11) Summary of Air Pollutants from Area Sources.

(12) Combustion of Fuels, Stationary Sources.

(13) Transportation Sources.

(14) Process Losses.

(15) Emissions from Evaporative Losses.

(16) Emissions from Solid Waste Disposal.

(17) Point Source Emissions.

(18) Area Source Emissions (272 grids).

(19) Annual Fuel Consumption (by counties).

(20) Housing Units (by jurisdictions).

(21) Population, Housing Units (by grids).

(22) Emission Densities (tons/km^2).

(23) Flights per year (various airports).

Samples from the inventory are shown in Figures A-5 through A-10, Appendix A.

5. NEDS Inventory-1973

The inventories discussed so far show the gradual evolvement of the techniques for collecting and processing inventory data. The earliest inventory, the IPP inventory, contained information on only two pollutants, sulfur dioxide and particulates, while subsequent inventories include also data on carbon monoxide, hydrocarbons, and oxides of nitrogen. The data collection methods have also become more reliable. For the IPP inventory, information on area source emissions was obtained from gross estimates on fuel delivery and consumption for the entire area under study. The use of the rapid survey technique for the DAQED inventory, which breaks down the information into geographic areas of the community and makes use of formulas using degree-days (a unit representing the deviation from the mean ambient temperature--65°F--for one day), the number and size of dwellings, and other refinements, provided considerably more accurate estimates of emissions from area sources. Similar techniques were used for all subsequent inventories.

A comparison of the presentations of data shows an increasing degree of sophistication and usefulness indicated by the various ways in which the data are broken down and presented, for example, in the NATO inventory.

The actual emissions of pollutants shown in the tabulations have been continuously updated to reflect current practices as new sources came into being or to reflect the installation and effect of control equipment. For this reason, the inventories currently maintained by the local and state regulatory agencies, such as the Saint Louis City or County Air Pollution Control Office, are the only ones which can be used for the purposes of RAPS. The data in these inventories, some of which are in the form of computer printouts (others are on Inspectors' Report Sheets), have recently (Summer 1973) been acquired and entered into the National Emission Data Systems (NEDS) inventory. The characteristics of this inventory system, presented in APTD-1135, "A Guide for Compiling a Comprehensive Emission Inventory,"[14] are discussed below.

The NEDS was created by the EPA Office of Air Programs to provide a uniform format for source inventory data on a national scale. It consists of a number of separate files suitable for computerized processing and has provisions for storing data for both point and area systems as well as separate files containing various input/output, maintenance, and editing programs. The concept is shown in Figure 6.

The system distinguishes between point sources (emitting at least 100 tons per year) and area sources for the primary pollutants: particulates, SO_2, CO, hydrocarbons, and NO_x. The decision to designate sources emitting more than 100 tons per year of primary pollutants as point sources is based on the estimate that a 100-tons-per-year source would produce, under average meteorological conditions, an ambient concentration of about 5 to 8 micrograms of pollutant per cubic meter. This is about 10 percent of the secondary annual federal air quality standard for SO_2 or particulates. (Page 10-2 of APTD-1135.[14])

In addition, about 70 compounds or categories of industrial sources are designated as point sources regardless of quantities of emissions.

A point source is defined, therefore, as any emitting point or plant or facility whose summation of emitting points totals 100 tons or more per year of any one of the five primary pollutants: CO, SO_2, NO_x, particulates, or hydrocarbons; or as any of the pollutant sources listed below, regardless of quantity of emissions.

- Chemical process industries: adipic acid, ammonia, ammonium nitrate, carbon black, charcoal, chlorine, detergent and soap, explosives (TNT and nitrocellulose), hydrofluoric acid, nitric acid, paint and varnish manufacturing, phosphoric acid, phthalic anhydride, plastics manufacturing, printing ink manufacturing, sodium carbonate, sulfuric acid, synthetic fibers, synthetic rubber, terephthalic acid.
- Food and agricultural industries: alfalfa dehydrating, ammonium nitrate, coffee roasting, cotton ginning, feed and grain, fermentation processes, fertilizers, fish meal processing, meat smoke houses, starch manufacturing, sugar cane processing.

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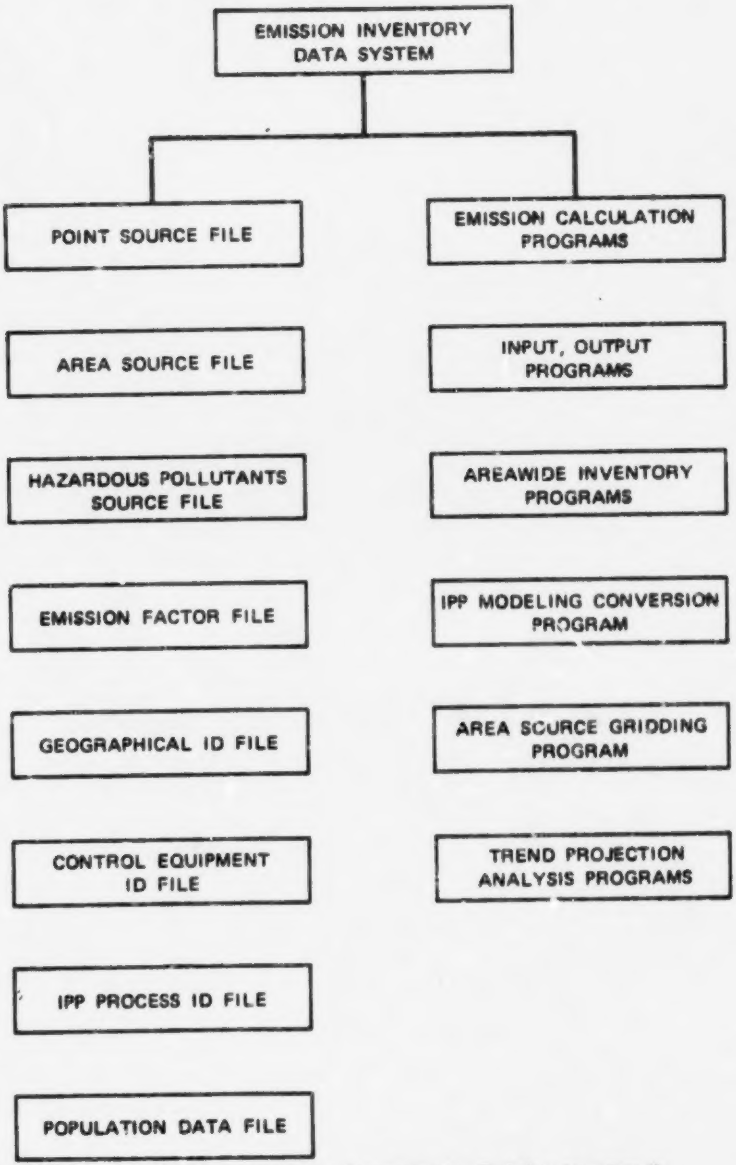
EMISSION INVENTORY DATA SYSTEM
POINT SOURCE FILE
AREA SOURCE FILE
HAZARDOUS POLLUTANTS SOURCE FILE
EMISSION FACTOR FILE
GEOGRAPHICAL ID FILE
CONTROL EQUIPMENT ID FILE
IPP PROCESS ID FILE
POPULATION DATA FILE
EMISSION CALCULATION PROGRAMS
INPUT, OUTPUT PROGRAMS
AREAWIDE INVENTORY PROGRAMS
IPP MODELING CONVERSION PROGRAM
AREA SOURCE GRIDDING PROGRAM
TREND PROJECTION ANALYSIS PROGRAMS

SOURCE: "Guide for Compiling a Comprehensive Emission Inventory," Environmental Protection Agency (1972).

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FIGURE 6 EMISSION INVENTORY SYSTEM CONCEPT

- Metallurgical industries: aluminum ore reduction, copper smelters, ferroalloy production, iron and steel mills, lead smelters, metallurgical coke manufacturing, zinc (primary metals industries); aluminum operations, brass and bronze smelting, ferroalloys, gray iron foundries, lead smelting, magnesium smelting, steel foundries, zinc processes (secondary metal industries).
- Mineral products industries: asphalt roofing, asphaltic concrete batching, bricks and related clay refractories, calcium carbide, castable refractories, cement, ceramic and clay processes, clay and fly ash sintering, coal cleaning, concrete batching, fiberglass manufacturing, frit manufacturing, glass manufacturing, gypsum manufacturing, lime manufacturing, mineral wool manufacturing, paperboard manufacturing, perlite manufacturing, phosphate rock preparation, rock, gravel, and sand quarrying and processing.
- All petroleum refining and petrochemical operations.
- All wood processing operations.
- Petroleum storage (storage tanks and bulk terminals).
- Miscellaneous: fossil fuel steam electric power plants, municipal or equivalent incinerators, open burning dumps.
- Hazardous pollutant sources.

Another category of point sources, regardless of quantities of emissions, are pollutants designated as hazardous. A list of these is still in preparation.

The location of all point sources is described using Universal Transverse Mercator (UTM) coordinates. This system, designed by the U.S. Army[15] provides projections of square grid zones with convenient measuring units. The system has the advantage of continuity and uniformity for the country, and it is rapidly becoming the accepted system of base coordinates for a body of technical information.

The NED System contains other files beside the source inventory. These are

- The Population Data File, which contains such information as number of household units in an area, number of manufacturing employees, number of retail and wholesale establishments. This information is used to calculate emissions where no direct data are available, as for example, emissions resulting from solid wastes, fuel consumption for space heating, and others.

- The Emission Factor File, which contains conversion factors that provide an estimate of the production of a given pollutant by a process or activity. For example, it has been estimated that two pounds of solvent per person per year are emitted from dry cleaning plants in moderate climates. In conjunction with appropriate population data contained in the Population Data File, the total amount of hydrocarbons per unit area can thus be calculated. The most complete collection of factors has been published by EPA in the Compilation of Air Pollutant Emission Factors (AP-42).
- The Control Equipment File, which contains information on types and efficiencies of various control devices.

As indicated in Figure 6, the NED System contains a number of programs; these include not only "housekeeping" programs, such as those for input and output, editing, and emission calculation, programs permitting outputs by area, source classification, and pollutant, as well as conversion programs selecting data for implementation planning programs and trend analysis.

The system is designed to provide data on annual emissions of pollutants; estimates of shorter emission rates--weekly, daily, or hourly--can be calculated automatically by applying appropriately resolved production throughput, or other control data to the base emission figure. Such an approach can provide the time resolution necessary for RAPS where no actual hourly measurements are available. Typical printouts are shown in Figures A-11 and A-12 in Appendix A.

Table 17 shows a comparison of the various emission inventories. Only limited conclusions can be drawn from a comparison of these data. The data in the IBM inventory, covering a much more limited area, are not comparable at all; nor do the other inventories cover exactly the same territory. The data shown for the NEDS inventory have been adjusted to include only the counties included in the two NATO inventories; thus, these three inventories are directly comparable. Good agreement is shown for sulfur oxides (if a correction of about 100,000 tons per year, corresponding to the SO_2 emissions of Franklin County, is added to the IPP and DAQED figures). The figures for the total emission of particulates and carbon monoxide are much higher in the NEDS inventory than in the older inventories; the emission values for hydrocarbons and nitrogen oxides again show quite good agreement (the contribution from Franklin County is fairly small).

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Table 17

COMPARISON OF EMISSION INVENTORIES FOR THE METROPOLITAN SAINT LOUIS INTERSTATE AIR QUALITY REGION*

Inventory Name	Data Base Year	Area*	Emission Inventory Technique	Emission Totals (tons/year)				
				Sulfur Oxides	Partic- ulates	Carbon Monoxide	Hydro- carbons	Nitrogen Oxides
IPP	1968	Franklin County not included	IPP forms filled out by local agencies from questionnaires (Mo.) or letters of intent (Ill.)	612,318	192,800			
IBM	1970	Madison County, Franklin County, Saint Clair County and Monroe County not included	IPP point source data (1968) updated)		Not	comparable		
DAQED	1967 to 1968	Franklin County and Monroe County not included	Rapid survey	662,490	186,290	1,644,640	326,280	180,780
NATO -1	1969	----	Updated IPP data	746,160	185,910	1,417,460	187,650	218,610
NATO -2	1969	----	Updated IPP data New emission factors	744,930	184,970	1,865,720	288,430	295,340
NEDS	1972†	----	Updated IPP data	757,105	347,379	3,803,460	282,982	298,491

*Includes the following jurisdictions, except as noted: Jefferson County, Saint Charles County, Saint Louis County, St. Louis City, Franklin County, Madison County, Monroe County, Saint Clair County.

†The data were put into NEDS in 1973, but were based on earlier years. NEDS is updated every 6 months.

The inventories are too close in time to allow any clear trends to show up. The differences are probably better viewed as examples of changes produced by better inventory techniques. Even so, closer examination of NEDS data shows examples of values that suggest the desirability of rechecking the data; for example, a CO emission of 1,340,000 tons from a single blast furnace or evaporation of 14,000 tons from a single tank suggests a check. The former amounts to almost 35 percent of the total estimated emission of carbon monoxide for the air quality control region; if correct, it will certainly affect the view of carbon monoxide as a pollutant whose origin is primarily related to traffic sources.[*]

As the NEDS inventory represents the current understanding of emissions in the Saint Louis area, it could and should be used for planning purposes. For example, it can serve as a basis for the determination of the number of point sources that should be monitored for the RAPS emission inventory, since only the most important point sources can be monitored. A review of the point sources listed in the NEDS inventory shows the breakdown of point sources by size in Table 18 and Figure 7.

Table 18

NUMBER OF POINT SOURCES

Pollutant	Emission Category (tons/year)			
	> 10[*]	$> 10^{2}$[†]	$> 10^{3}$[†]	$> 10^{4}$[†]
Particulates	271	99	28	6
SO$_x$	345	184	67	13
NO$_x$	352	111	24	7
HC	269	99	23	1
CO	93	31	11	6

[*] Data from NEDS printout of 19 December 1973. Includes some sources not in earlier printouts.

[†] Data from NEDS printout of 28 August 1973.

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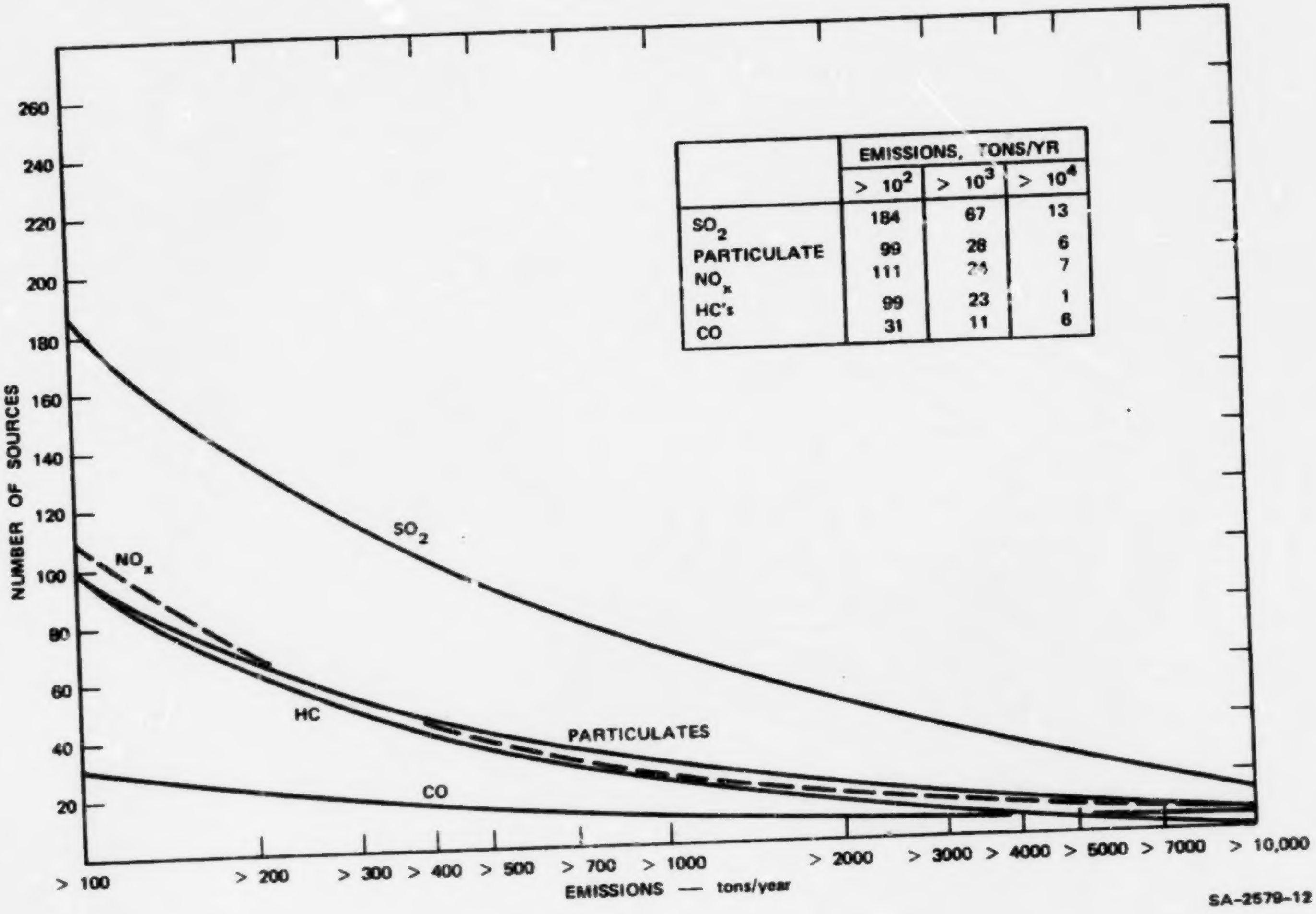
[*] Both of these figures are erroneous (Personal Communication, Illinois Environmental Protection Agency, December 1973).



	EMISSIONS, TONS/YR		
	> 10^2	> 10^3	> 10^4
SO$_2$	184	67	13
PARTICULATE	99	28	6
NO$_x$	111	24	7
HC's	99	23	1
CO	31	11	6

FIGURE 7 NUMBER OF POINT SOURCES AND EMISSIONS

This information is even more relevant if it is arranged to indicate what percentage of total emissions can be evaluated by monitoring a given number of sources. By referring to Figures 8 through 12, we see that we can monitor, say, 90 percent of all emissions from point sources greater than 1 ton/year by observing about 40 sources for SO_2, about 5 for CO, 50 for particulates, and 100 for hydrocarbons; oxides of nitrogen, however, would require the monitoring of 330 sources to achieve the 90 percent level. Alternatively, we could decide to use an emission of 100 tons per year as a cutoff point. In that case, 184 sources for SO_2, 31 sources for CO, 99 sources for particulates and hydrocarbons, and 111 sources for NO_x should be monitored. Table 19 summarizes.

As mentioned above (page 114) the 100 ton-per-year break point is consistent with a 10 percent sensitivity for modeling or measuring concentrations near the levels of the national secondary air quality standards. While this is probably equally suitable for the modeling verification studies of RAPS, the sensitivity of such multisource models to this break point should be investigated by specific studies as recommended above on pages 48-49.

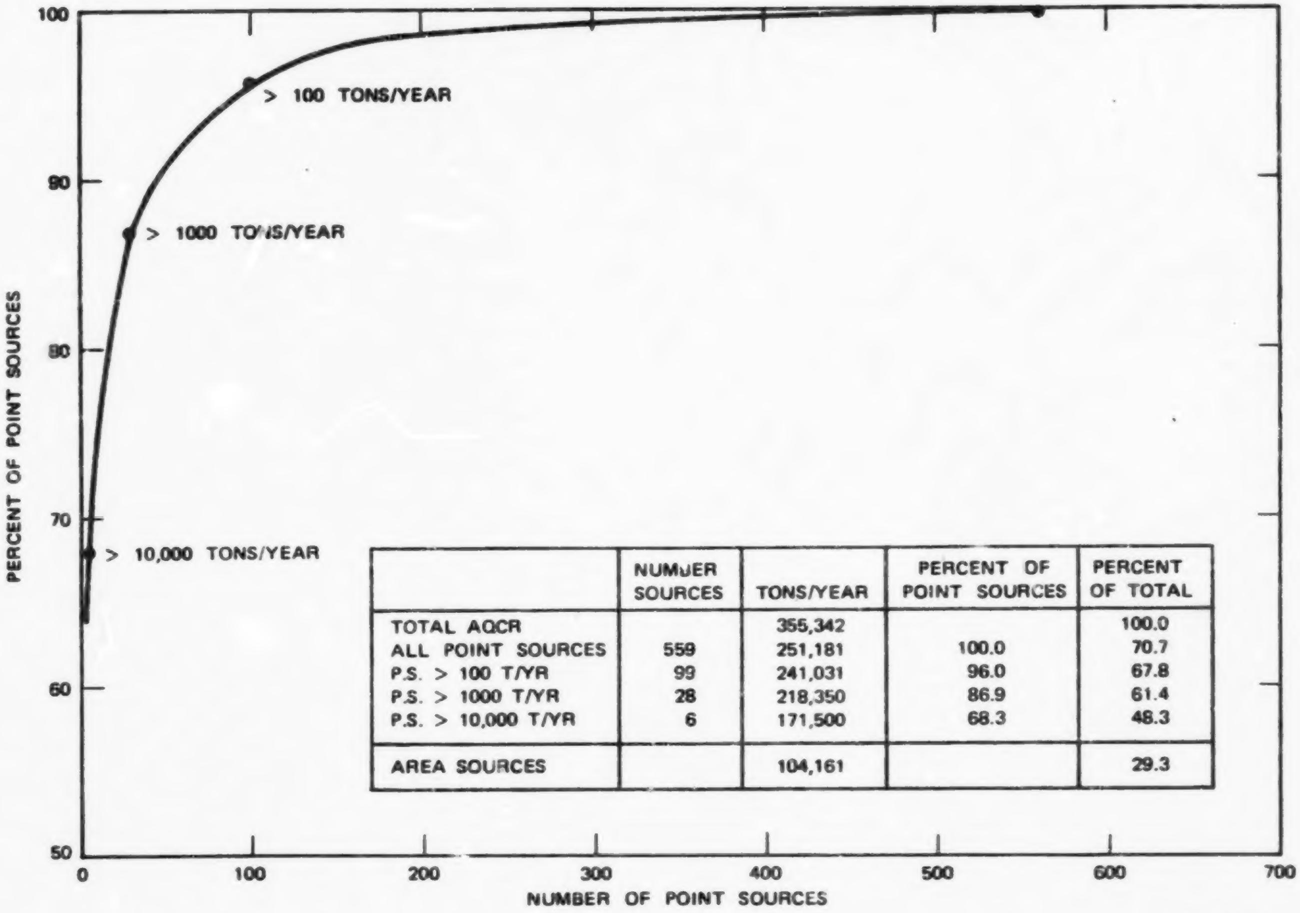
Table 19

NUMBER OF SOURCES MONITORED

Pollutant	Type of Inventory	
	90 Percent of Emissions from Point Sources	100 Tons per Year Inventory
SO_2	40	184
Particulates	50	99
CO	5	31
Hydrocarbons	99	99
NO_x	330	111

The above data can also be used to evaluate the relative importance, and thus the appropriate treatment, of area sources.

For example, if we assume that all sources emitting more than 100 tons per year of any pollutant will be monitored directly, the remaining point sources (that is, those emitting between 1 and 100 tons per year)



	NUMUER SOURCES	TONS/YEAR	PERCENT OF POINT SOURCES	PERCENT OF TOTAL
TOTAL AQCR		355,342		100.0
ALL POINT SOURCES	559	251,181	100.0	70.7
P.S. > 100 T/YR	99	241,031	96.0	67.8
P.S. > 1000 T/YR	28	218,350	86.9	61.4
P.S. > 10,000 T/YR	6	171,500	68.3	48.3
AREA SOURCES		104,161		29.3

SA-2579-13

FIGURE 8 PARTICULATE EMISSIONS FOR SAINT LOUIS AIR QUALITY CONTROL REGION

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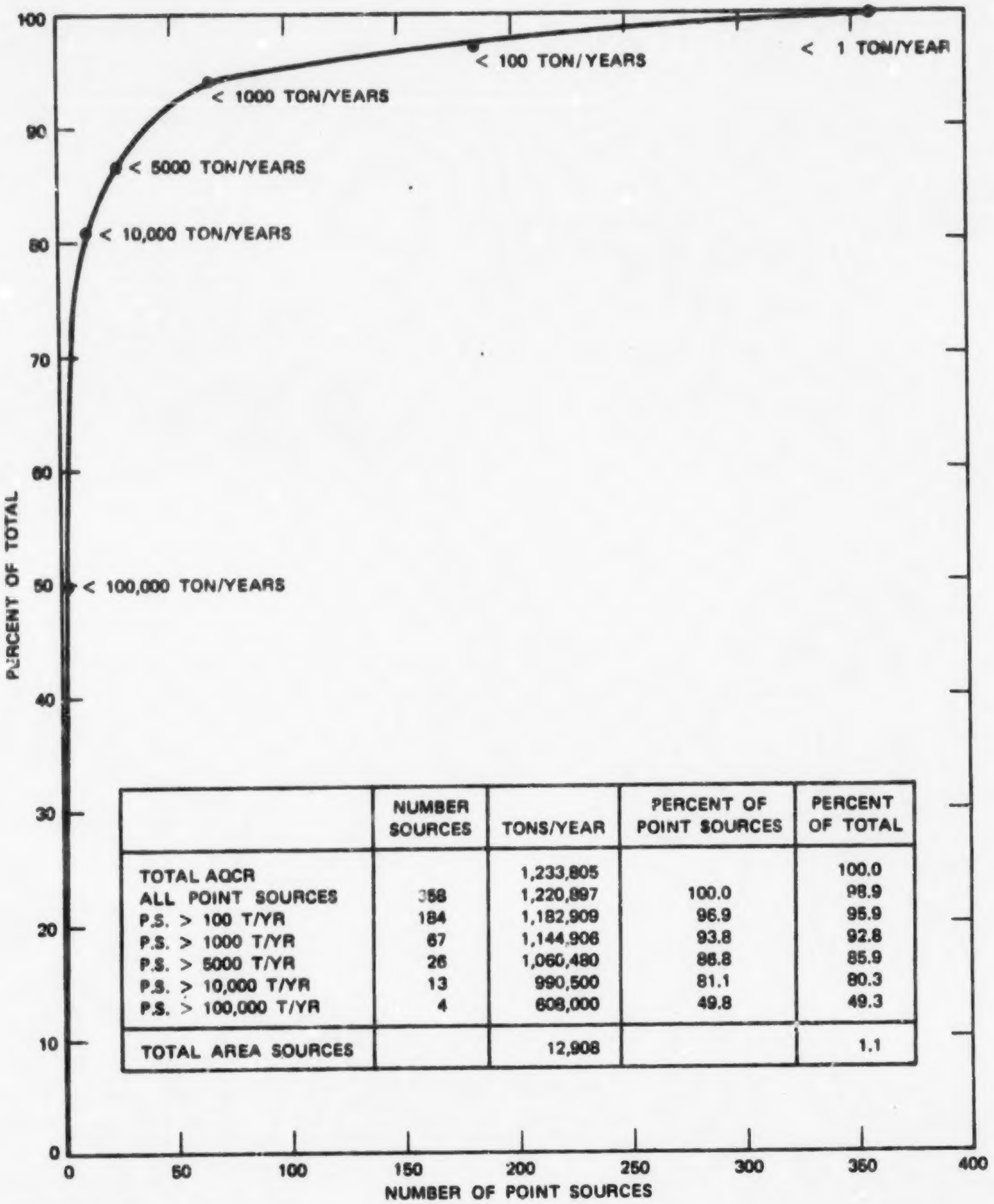

	NUMBER SOURCES	TONS/YEAR	PERCENT OF POINT SOURCES	PERCENT OF TOTAL
TOTAL AQCR		1,233,805		100.0
ALL POINT SOURCES	358	1,220,897	100.0	98.9
P.S. > 100 T/YR	184	1,182,909	96.9	95.9
P.S. > 1000 T/YR	67	1,144,906	93.8	92.8
P.S. > 5000 T/YR	26	1,060,480	86.8	85.9
P.S. > 10,000 T/YR	13	990,500	81.1	80.3
P.S. > 100,000 T/YR	4	608,000	49.8	49.3
TOTAL AREA SOURCES		12,908		1.1

SOURCE: NEDS Inventory (1973).

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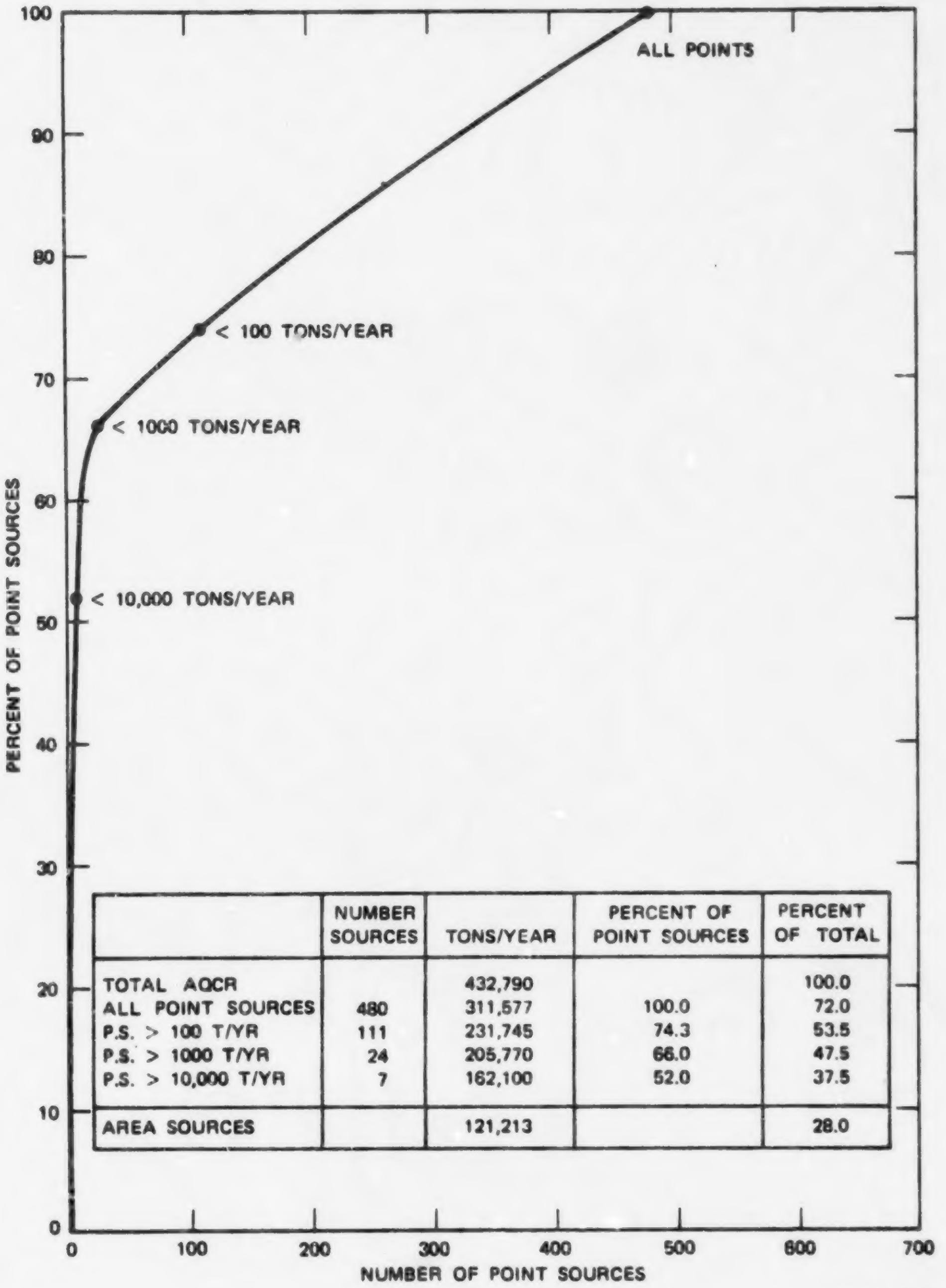
FIGURE 9 SO_2 EMISSIONS FOR THE SAINT LOUIS AIR QUALITY CONTROL REGION



	NUMBER SOURCES	TONS/YEAR	PERCENT OF POINT SOURCES	PERCENT OF TOTAL
TOTAL AQCR		432,790		100.0
ALL POINT SOURCES	480	311,577	100.0	72.0
P.S. > 100 T/YR	111	231,745	74.3	53.5
P.S. > 1000 T/YR	24	205,770	66.0	47.5
P.S. > 10,000 T/YR	7	162,100	52.0	37.5
AREA SOURCES		121,213		28.0

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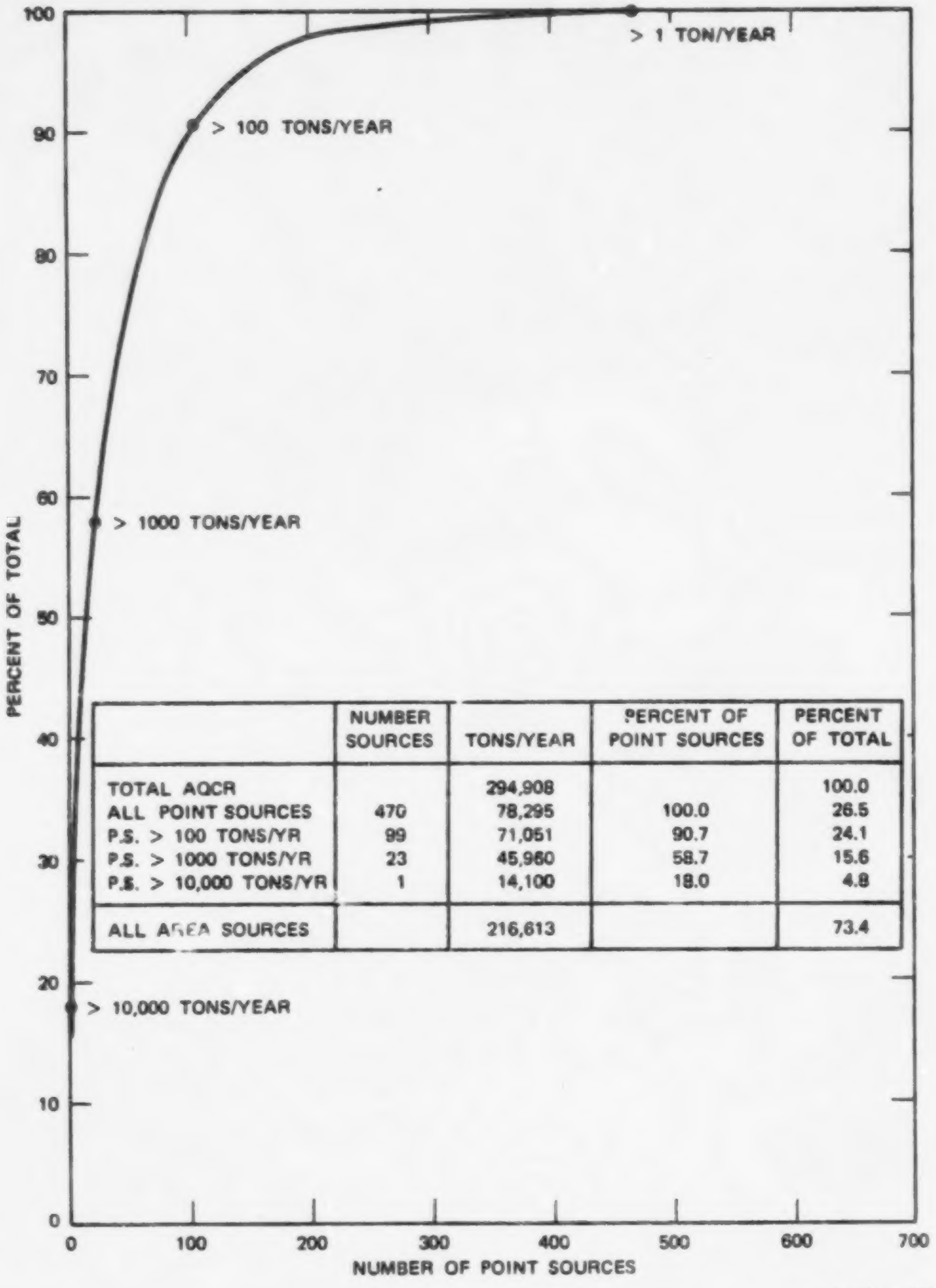
FIGURE 10 NO_x EMISSIONS FOR THE SAINT LOUIS AIR QUALITY CONTROL REGION



	NUMBER SOURCES	TONS/YEAR	PERCENT OF POINT SOURCES	PERCENT OF TOTAL
TOTAL AQCR		294,908		100.0
ALL POINT SOURCES	470	78,295	100.0	26.5
P.S. > 100 TONS/YR	99	71,051	90.7	24.1
P.S. > 1000 TONS/YR	23	45,960	58.7	15.6
P.S. > 10,000 TONS/YR	1	14,100	18.0	4.8
ALL AREA SOURCES		216,613		73.4

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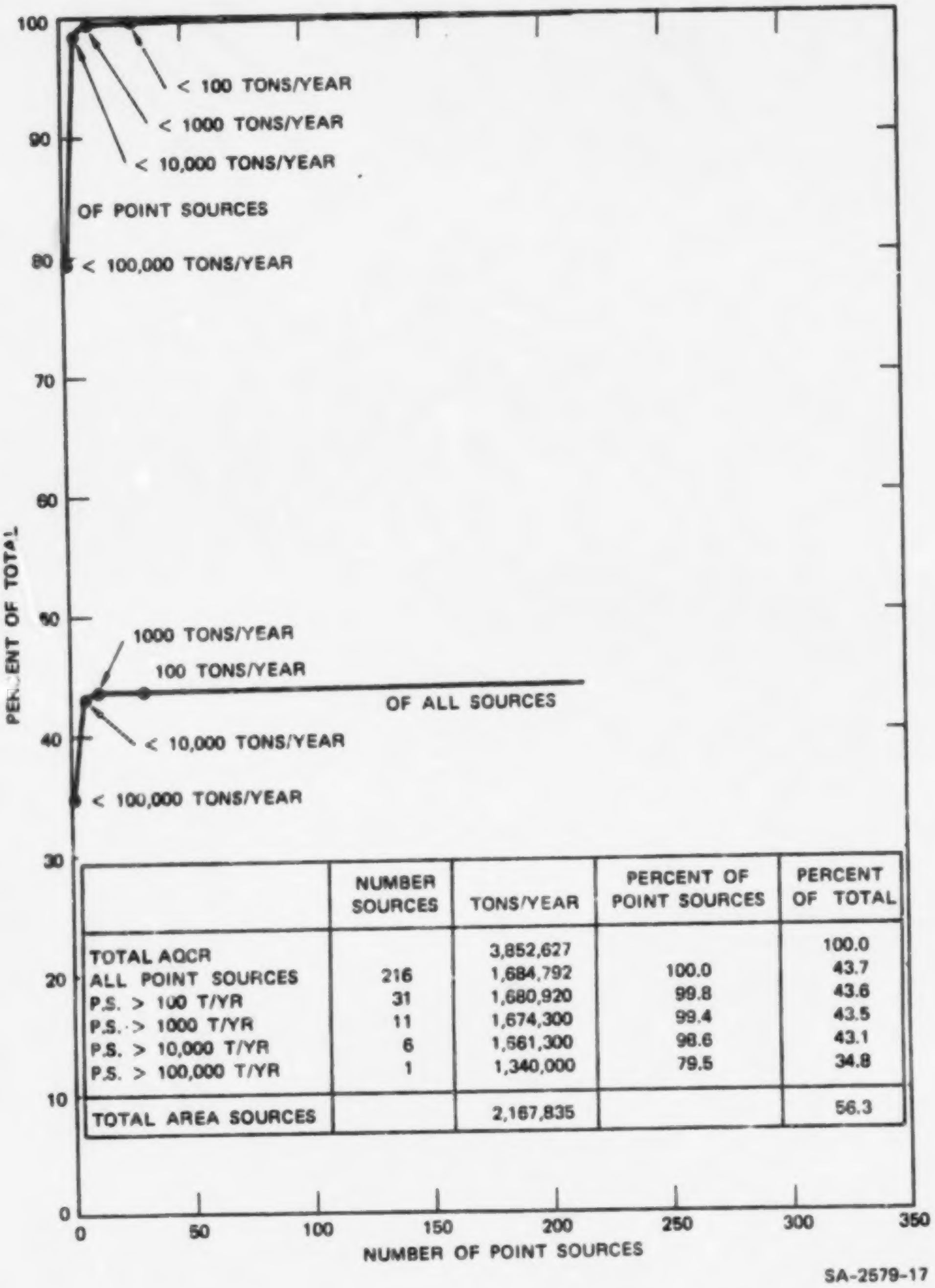
FIGURE 11 HYDROCARBON EMISSIONS FOR THE SAINT LOUIS AIR QUALITY CONTROL REGION



	NUMBER SOURCES	TONS/YEAR	PERCENT OF POINT SOURCES	PERCENT OF TOTAL
TOTAL AQCR		3,852,627		100.0
ALL POINT SOURCES	216	1,684,792	100.0	43.7
P.S. > 100 T/YR	31	1,680,920	99.8	43.6
P.S. > 1000 T/YR	11	1,674,300	99.4	43.5
P.S. > 10,000 T/YR	6	1,661,300	98.6	43.1
P.S. > 100,000 T/YR	1	1,340,000	79.5	34.8
TOTAL AREA SOURCES		2,167,835		56.3

FIGURE 12 CO EMISSIONS FOR THE SAINT LOUIS AIR QUALITY CONTROL REGION

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will be assigned to area sources. For purposes other than those of the emission inventory itself, it may be desirable to monitor directly a few point sources emitting less than 100 tons per year. Thus, a source located near an air quality monitoring station may be monitored directly to aid in evaluating the measurements from the station, and would, therefore, be treated as a point source rather than included as an area source. In addition to these minor point sources, the area sources also contain emissions of totally diffuse origin (mainly traffic, but also domestic heating). The hourly distribution patterns of these two types of sources are different. It thus becomes necessary to establish the distribution patterns of minor point sources if they amount to a significant fraction of the total area emissions.

Table 20 shows the breakdown of minor point sources in relation to diffuse area sources. The data indicate, for example, that minor point sources are an important component of area SO_2 emissions (75 percent) and small fractions of CO, hydrocarbon, and particulate emissions. On the other hand, only in the case of NO_x do minor point sources constitute an appreciable fraction (18.4 percent) of the total emissions of the Saint Louis area.

Thus, a realistic decision can be reached in the framework of actual emissions in the Saint Louis area.

C. Traffic and Transportation Inventories

1. Streets and Highways

A comprehensive study of surface transportation in the Saint Louis area was initiated in 1965 by the East-West Gateway Coordinating Council in cooperation with the State Highway Commission of Missouri, the Illinois Department of Transportation, and related federal and local agencies. The purpose of the study was to develop a balanced, multimodal transportation plan for the period extending to 1990 based on forecasts of socioeconomic and land use data.

As part of this program, traffic volume data were gathered and appropriate traffic maps were prepared. Average daily traffic counts were obtained for all major streets and highways in the City of Saint Louis, Saint Louis County, and portions of Saint Charles, Franklin, and Jefferson Counties in Missouri and Madison, Monroe, and Saint Clair Counties in Illinois. The following functional definitions were used for classification purposes:

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Table 20

BREAKDOWN OF AREA SOURCES

	Number	Emissions (tons/year)	Percent of Point Sources	Percent of All Sources	Remaining Point Sources as Percent of Area Sources
SO_2					
Remaining point sources > 1 ton/year	174	37,988	3.1%	3.1%	75 %
Area sources		12,908		1.1	
Total		50,876		4.1%	
CO					
Point sources > 1 ton/year	185	3,872	0.2%	0.1%	0.2%
Area sources		2,167,835		56.3	
Total		2,171,707		56.4%	
NO_x					
Point sources > 1 ton/year	369	79,832	25.6%	18.4%	39.6%
Area sources		121,213		28.0	
Total		201,245		46.5%	
HC					
Point sources > 1 ton/year	371	7,244	9.2%	2.5%	3.3%
Area sources		216,613		73.4	
Total		223,857		75.9%	
Particulates					
Point source > 1 ton/year	460	10,150	4.0%	2.9%	9.0%
Area sources > 1 ton/year		104,161		29.3	
Total		114,311		32.2%	

- Freeways and expressways are high-volume, high-speed highways designed to carry about 12,000 vehicles per lane per day at speeds of 35 to 50 miles per hour. All cross traffic is carried on separate levels, and there are no traffic signals.
- Principal arterials carry large volumes of traffic between different parts of the urban system and connect to the freeway system. Typically, they carry 6,000 vehicles per lane per day at average speeds of 25 to 35 miles per hour. Minor arterials carry traffic between the principal arterial network; they also serve as local streets. They frequently carry up to 6,000 vehicles per lane per day at speeds of 20 to 30 miles per hour.
- Local streets provide access to all areas. They vary in design capacity.

Data were gathered for all freeways and major and minor arterials. Street names were alphabetized, and segments were designated by intersections (not by UTM coordinates). The resulting data are shown graphically on a traffic map in Figure 13, and they are updated yearly by the Missouri and Illinois traffic authorities.

2. Railways and Vessels

The U.S. Department of Transportation is planning three transportation studies in the Saint Louis area, as a part of the Saint Louis Air Pollution Studies. The goal of these studies is to ascertain the air pollution attributable to railways and vessels in addition to quantifying the emissions from specific transportation systems and facilities. The studies are being coordinated with EPA's Regional Air Pollution Study.

The first of these studies deals with waterborne vessels, which constitute a portion of the mobile pollution sources of the Saint Louis area. A comprehensive listing of sources, such as tugboats, tankers, recreational vessels, and so forth, will be organized by engine horsepower. The frequency of usage will be determined, and the pollutant emission calculated using appropriate emission factors. If the data appear to warrant additional investigation, increasingly accurate inventories are planned according to the scheme shown in Table 21.

A similar study is planned for rail operations in the Saint Louis area. Rail activity in the region has been studied for many years. The Transportation Systems Center, DoT, recently estimated annual surface

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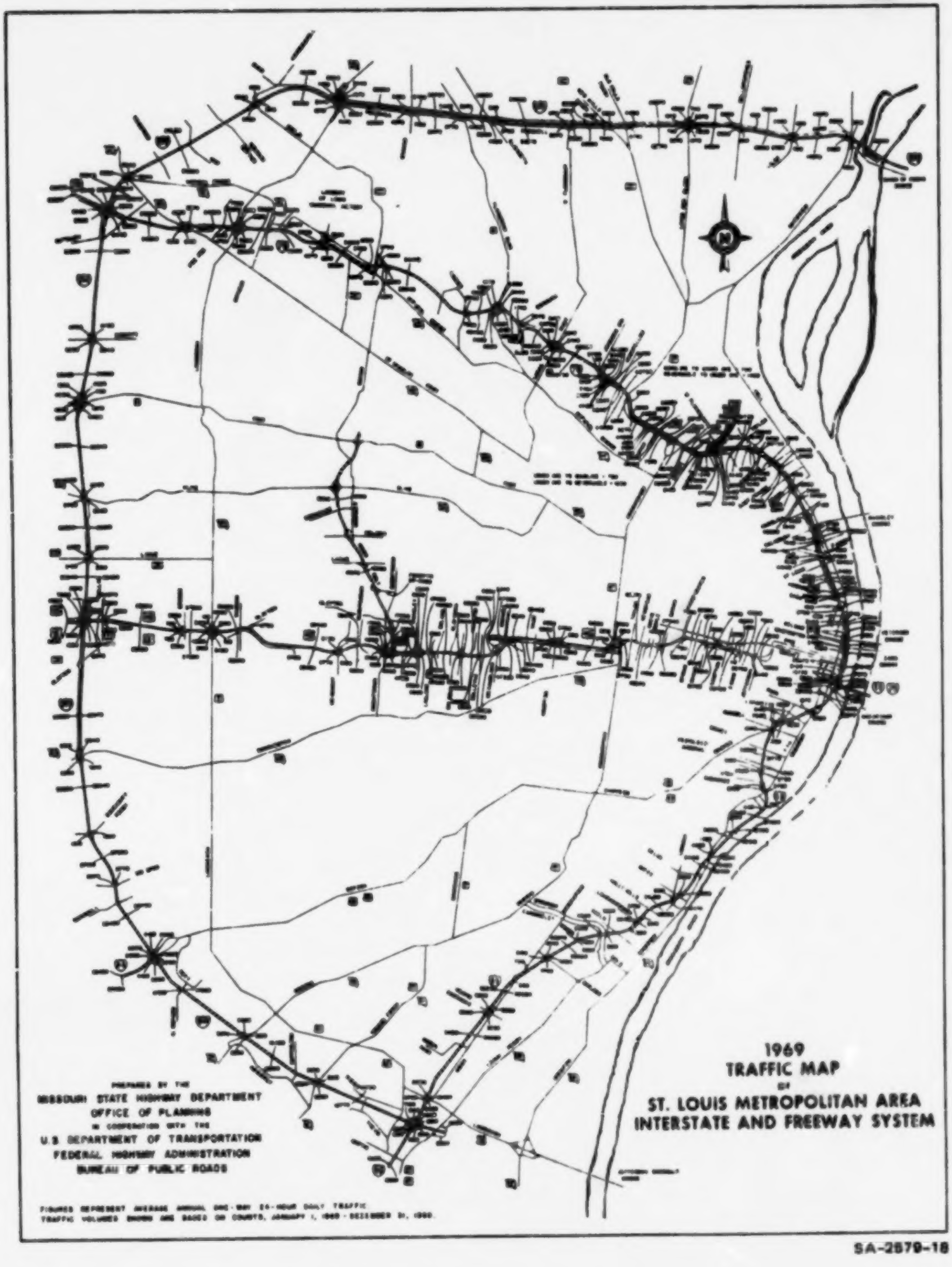
1969
TRAFFIC MAP
OF
ST. LOUIS METROPOLITAN AREA
INTERSTATE AND FREEWAY SYSTEM
PREPARED BY THE
MISSOURI STATE HIGHWAY DEPARTMENT
OFFICE OF PLANNING
IN COOPERATION WITH THE
U.S DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
BUREAU OF PUBLIC ROADS
FIGURES REPRESENT AVERAGE ANNUAL ONE-WAY 24-HOUR DAILY TRAFFIC
TRAFFIC VOLUMES SHOWN ARE BASED ON COUNTS, JANUARY 1, 1969 - DECEMBER 31, 1969.

SA-2579-18

FIGURE 13 1969 TRAFFIC MAP OF SAINT LOUIS METROPOLITAN AREA INTERSTATE AND FREEWAY SYSTEM

Table 21

CLASSIFICATION OF POSSIBLE EMISSION INVENTORIES*

Type Inventory	Source Description	Position Resolution	Time Resolution
Based on published data	Exhaust averages from literature	Region	Yearly average
Rapid survey	Exhaust averages calculated from operators duty cycles	Terminals Mainlines	Weekly/daily average
Comprehensive	Exhaust and evaporative averages from tests	Fine grid	Weekly average and possible daily maximums
Extensive field survey	Individual exhaust and evaporative tests	Fine grid	Weekly averages and possible hourly maximums

---

*Source: "Air Pollution Guidelines," NATO Committee on Challenges of Modern Societies (1971).

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Table 22

1967 EMISSIONS FROM RAIL OPERATIONS WITHIN 100 MILES OF SAINT LOUIS

Pollutant	10^3 lb
Particulates	97
SO_2	253
CO	273
HC	195
NO_x	292
Aldehydes	16
Organic acids	27
Total	1,153

Source: J. C. Sturm, "Railroads and Air Pollution: A Perspective," Report No. FRA-RT-73-33, U.S. D.O.T. Federal Railroad Administration, Washington, D.C. (May 1973).

freight transportation exhaust emissions within 100 miles of Saint Louis. These estimated rail exhaust emissions for 1967 are shown in Table 22.

The rail source emission inventory will describe

- The quantity of emissions by source type
- The location of the sources
- The time pattern.

As in the case of the vessel inventory, a series of inventory methodologies will be used (similar to the ones shown in Table 21) starting with a review of published data on rail operations and standard

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emission factors. Subsequent inventories with increasing refinements in location, emission, and time factors are planned for those pollutants whose emissions appear to be of sufficient magnitude to warrant further investigation.

A separate study of emissions from Saint Louis railway terminals is also planned. This study will concern itself not only with emissions from locomotives, but also with emissions from stationary sources at terminals, such as power plants, fuel storage, incinerators, and with operational factors, such as freight handling by trucks or cargo spillage.

D. Summary

The requirements of accuracy and spatial and temporal resolution that the RAPS emission inventory should exhibit are not met by any of the existing inventories. The first four inventories--the IPP, IBM, DAQED, and NATO emission inventories--are essentially of only historical interest.

The NEDS inventory contains the best current estimates, and it constitutes a useful data base for those emission sources that, for practical reasons, cannot be individually measured or closely simulated by emission modeling. It can serve as a base for the determination of the scope of the task, since it details the source size and the descriptions of location, normal operating schedule, source classification code number, and stack parameters.

It certainly could meet the requirement for long-term data on a wide range of pollutants. For model verification purposes for a limited range of pollutants, the content of the NEDS inventory is, however, inadequate since it only gives annual emission data and does not provide sufficiently detailed information for the determination of hourly emissions of sufficient precision even with the application of appropriate models.

Data on traffic and transportation are in part contained in the area source emission data of NEDS. For freeways and major arteries, which will be treated as line sources, these data will have to be supplemented by information on the traffic mix, average speed, type of roadway, and other factors.

EPA-450/3-74-054

REGIONAL AIR POLLUTION STUDY POINT SOURCE METHODOLOGY AND INVENTORY

by

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Office of Air and Waste Management
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Research Triangle Park, N. C. 27711

October 1974

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Publication No. EPA-450/3-74-054

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RAPS POINT SOURCE EMISSION INVENTORY METHODOLOGY

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RAPS POINT SOURCE EMISSION INVENTORY METHODOLOGY

1. Introduction

An emission inventory constitutes the starting point for any attempt to control emissions to the atmosphere. As long as such controls deal with average yearly concentrations, inventories giving total annual emissions of the various sources of pollutants are sufficient. The Regional Air Pollution Study has, however, as its first goal the validation of atmospheric dispersion models, which attempt to predict ambient pollutant concentrations on an hourly basis. Therefore, emission values derived from total annual emissions are largely inadequate, and the RAPS emission inventory was conceived to provide the needed time resolution and accuracy by measuring and recording hourly emissions (or parameters directly related to hourly emissions) and/or individualized hourly estimates derived for the principal sources of pollution. Thus, the emission inventory for the Regional Air Pollution Study (RAPS) at St. Louis is distinguished from existing emission inventories by two factors: its time and space resolution and its accuracy.

Although ultimately such an inventory should include all pollutants of importance, as a matter of priority, emphasis of the data collection will be placed on the two major pollutants of prime importance for modeling purposes, SO_2 as an indicator of pollution originating from stationary sources, and CO for mobile sources. Hourly measurement and estimates would provide the needed time resolution and, at the same time, increase the accuracy of the emission inventory by updating it. Later, the inventory can be expanded to include hydrocarbons (or organics), oxides of nitrogen, particulate matter, heat emissions and others.

Any attempt to obtain measured values for a large number of sources is a complex and expensive undertaking. Within the usual constraints of air pollution studies, such an approach is not feasible, and the use of algorithms or models has been generally resorted to for estimation of emissions. Since such emission models again describe assumed conditions, their use in the RAPS is less desirable and they will be used only where it does not impair the overall accuracy of the inventory, as indicated by a sensitivity analysis.

This report proposes an approach to the problem of assembling a "precision" inventory for the St. Louis Interstate Air Quality Region. It states the nature of the problem and the rationale for choosing the St. Louis area as a "test chamber"; the pollutants of interest are also discussed briefly. Using an approach suggested by NADB's Weighted Sensitivity Analysis Program, limits were placed on the scope of the investigation, which were then applied to the actual situation in St. Louis. The mechanism for the acquisition of data and their preparation prior to entry into a data bank, as well as a time schedule to accomplish these aims, are also described.

II. The Saint Louis Interstate Air Quality Control Region (SLIAQCR)

The St. Louis area was selected on the basis of careful considerations of the various factors of importance for a regional air pollution study(1). Standard Metropolitan Statistical Areas (SMSA's) were used as a basis for the analysis, and all SMSA's with population in excess of 400,000 were examined. The primary factors considered in the selection were:

- ° Geographic isolation from other SMSA's
- ° Location within the Continental climate zone
- ° Significant level and density of pollutant emissions
- ° Presence of a rural fringe with substantial crop lands
- ° Existence of control programs and historical data

The final selection of St. Louis was made by the Assistant Administrator for Research and Monitoring, EPA, from the four considered sites on the basis of the following rating (Table 1):

TABLE I

QUALIFICATIONS OF SELECTED SMSA'S

Criterion	Birmingham	Cincinnati	Pittsburgh	St. Louis
Surrounding area	Fair	Poor	Good	Good
Heterogeneous emissions	Fair	Fair	Fair	Good
Area size	Good	Good	Good	Good
Control program	Poor	Good	Good	Good
information	Poor	Good	Fair	Good
Climate	Good	Fair	Fair	Good

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(1) For details, see: Regional Air Pollution Study - A Prospectus, Part III, Research Facility, Standford Research Institute, 1972, Contract No. EPA 68-02-0207.

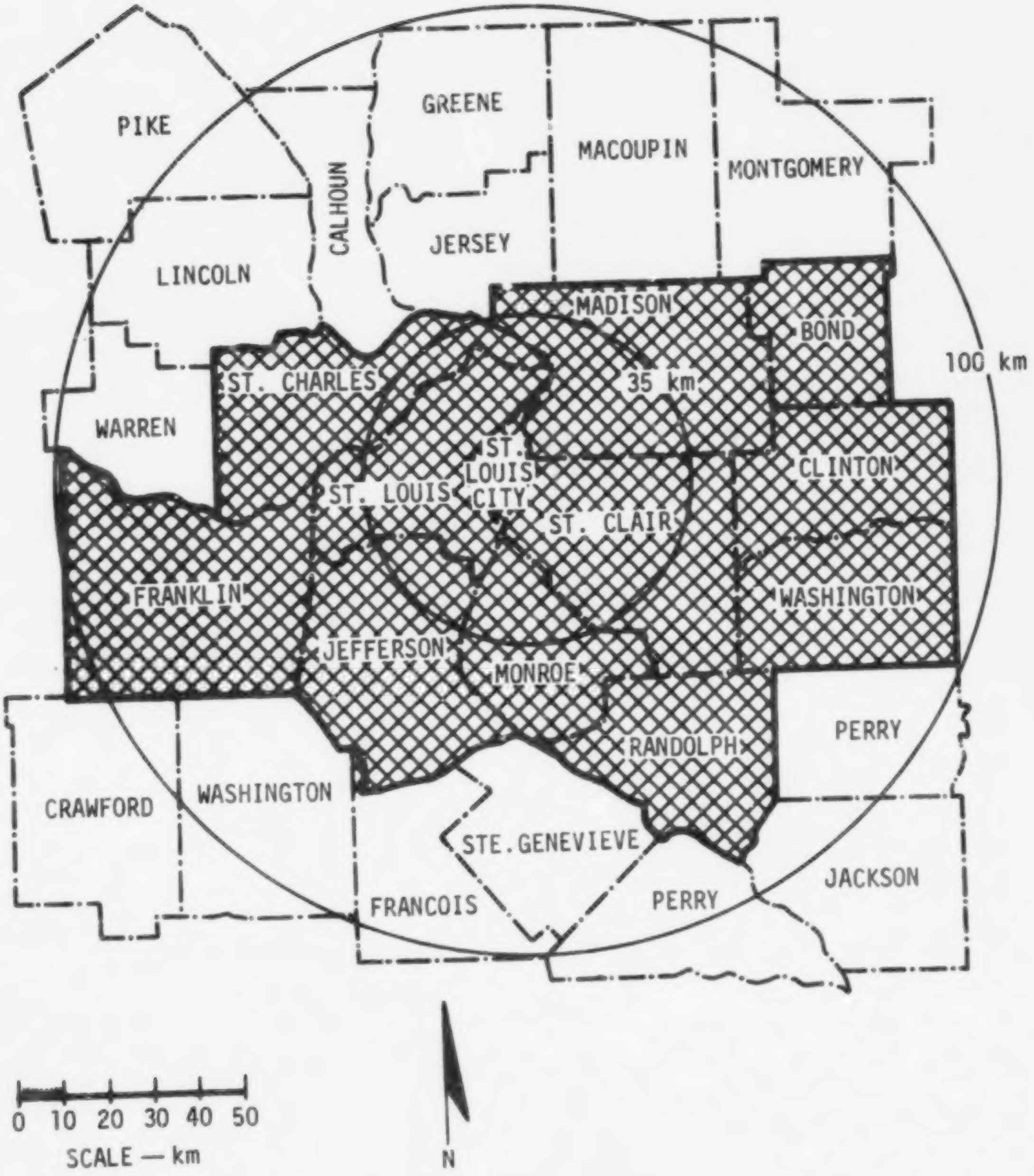
PIKE
GREENE
CALHOUN
MACOUPIN
MONTGOMERY
JERSEY
LINCOLN
MADISON
BOND
100 km
ST. CHARLES
35 km
WARREN
ST. LOUIS CITY
CLINTON
ST. LOUIS
ST. CLAIR
FRANKLIN
WASHINGTON
JEFFERSON
MONROE
PERRY
RANDOLPH
CRAWFORD
WASHINGTON
STE. GENEVIEVE
JACKSON
FRANCOIS
PERRY
0 10 20 30 40 50
SCALE — km
N

FIGURE 1 METROPOLITAN SAINT LOUIS INTERSTATE AIR QUALITY CONTROL REGION (SHADED AREAS ARE INCLUDED IN THE AQCR)

III. Sources of Air Pollution

A. Classification

Virtually every human activity results in some form and degree of air pollution. For practical purposes, it is convenient to classify the sources of emission; a general classification in shown in Table II. There, sources are divided into stationary and mobile, since these present significantly different problems. Stationary sources are further divided into Point and Area sources. The division between the two is arbitrary: sources tested individually become "Point Sources". For the RAPS inventory, sources emitting less than ten tons of pollutants per year will not be considered, at least initially, as individual points but rather assigned to and distributed over the appropriate area. Of course, even a very small point source can be a major contributor to a given local or nearby receptor (monitoring station), but the investigation of this problem constitutes a localized, special situation which needs to be dealt with separately from the overall inventory. Probably the only way the existence of a local interference can be determined is by examination of the records of each station.

The division of sources into combustion and non-combustion is again a matter of convenience; however, combustion sources constitute a specific group of emitters which, in some cases, like SO_2 for stationary sources or CO for mobile sources, constitute the overwhelming fraction of these pollutants.

B. Pollutants of Interest

The RAPS inventory is, initially, emphasizing "criteria" pollutants (for which Air Quality Standards exist) and, of those, primarily SO_2 and CO, since these are the ones which will be used at highest priority in the model validation studies. An attempt will also be made to inventory heat emissions. Ultimately the inventory will also include lesser pollutants such as trace and hazardous contaminants.

B.1 Sulfur Dioxide

Sulfur dioxide (SO_2) will be the pollutant initially emphasized in the inventory since it occupies the position of highest priority within the Regional Air Pollution Study. In St. Louis, virtually all of it (98.9%) is estimated to originate from listed point sources(2). Most of the SO_2 is produced by the combustion of coal and fuel oil, which average 3% and 1.5 - 2.5% of sulfur respectively, although some of it results from ore roasting, steel production, and

---

(2) Source: NEDS Inventory (1973)

TABLE II

CLASSIFICATION OF SOURCES FOR EMISSION INVENTORY

Source Category	Stationary Sources				Mobile Sources	
Source Subcategory	Area Sources		Point Sources		Area and Line Sources	
Source Process	Combustion	Noncombustion	Combustion	Noncombustion	Combustion	Noncombustion
Source units	Commercial Institutional Residential Small industrial Fuel Use Space heaters Water heaters Boilers Waste disposal--incinerators	Commercial Small industrial--Venting of organic vapors (dry cleaning, painting, gasoline storage and handling, food preparation)	Utilities Power plants Municipal--incinerators Industrial Boiler and power plants Indirect-fired air and process heaters Stationary internal combustion engines Stationary gas turbine engines Incinerators	Industrial Direct-fired process units All other industrial processes, material storage and handling	Surface vehicles Passenger cars Trucks and buses Commercial vehicles Railroads Vessels Off-highway vehicles and equipment Aircraft Piston engines Jet engines	Surface vehicles and aircraft Venting of fuel vapors Wear of tires and brakes
Pollutants	Gases and vapors SO_x NO_x CO Hydrocarbons and derivatives HCl HF Odors Particulates Fly ash and its specific chemical components Smoke	Gases and vapors Organic vapors (solvents, gasoline) Odors Particulates Organic aerosols Smoke	Gases and vapors SO_x NO_x CO Hydrocarbons and derivatives HCl HF Odors Particulates Fly ash and its specific chemical components Smoke	All pollutants	Gases and vapors SO_x NO_x CO Hydrocarbons and derivatives Odors Particulates Smoke Lead Oil aerosols Derivatives of fuel additives	Hydrocarbon vapors Particulates Organic Inorganic

Source: A Regional Air Pollution Study -
A Prospectus, Stanford Research
Institute, 1972.

petroleum refining operations. The largest contributors are the power generating stations of the utility companies. The six generating stations in the St. Louis area produce over 900,000 tons of SO_2 per year, or about 75% of all the SO_2 produced by point sources in the area.

Sulfur dioxide is relatively non-reactive in the atmosphere, at least over the time interval of a few hours, which is likely to be of interest to modelers. Removal from the atmosphere occurs by several mechanisms, some of which involve oxidation to sulfur trioxide with subsequent formation of sulfuric acid mist or sulfates by reaction with basic materials in the atmosphere (e.g., ammonia). These processes will have to be considered for long-term (24 hours or longer) modeling.

Available evidence indicates that the ratio of SO_2 to SO_3 in ambient air is between 50:1 to 100:1. Recent health data(3) indicate that (at least in the case of elderly patients with heart and lung diseases, as well as asthmatics) it is the level of suspended sulfates that correlates with adverse health effects rather than the SO_2 level. Best estimates indicate that sulfates are about an order of magnitude more irritating than SO_2. At this time, it is not clear whether sulfuric acid mist or sulfates are implicated, and the importance of atmospheric transformation products of SO_2 is not certain.

Ambient concentrations of SO_2 in the St. Louis atmosphere typically range from 20 to 40 micrograms/m^3 (annual average)(3).

B.2 Carbon Monoxide

Carbon monoxide (CO) is closely linked with automotive traffic. Stationary combustion sources normally generate only relatively minor amounts of CO. There are, however, a few important industrial sources of CO: the catalytic cracker regenerators in petroleum refineries, blast furnaces in steel mills, and certain chemical processes. And, because of the tremendous volume of stack gases generated by electric utilities, the relatively low concentrations of CO in these gases do contribute significantly to the overall CO concentration.

Carbon monoxide is chemically inert. It is removed slowly by contact with certain soil bacteria, which maintain the natural balance of CO in the air, but the rates of these processes are not significant on the time scale of interest.

---

(3) Health Consequences of Sulfur Oxides: CHESS 1970-71, U. S. Environmental Protection Agency, Office of Research & Development, EPA 65011-74-004.

Carbon monoxide combines with hemoglobin 200 times more readily than oxygen; it thus prevents the blood hemoglobin from transporting oxygen from the lungs to the tissues. Exposure to low concentrations (below 100 ppm or 115 mg/m^3) causes headaches and dizziness. Its actions are most likely to affect persons living at high altitudes and people with chronic heart and lung diseases. Cigarette smokers commonly have 5 - 10% carboxy-hemoglobin, an amount that corresponds to 30 to 60 ppm of CO in ambient air (35 to 70 mg/m^3).

Ambient concentrations of CO in the downtown St. Louis area range from 15 to 35 milligrams/m^3(4).

B.3 Particulate Matter

The fate of particulate matter in the atmosphere is becoming a major research target. It is a particularly difficult subject because the characteristics of particles are determined only partially by their chemical composition and very largely by their size distribution. Thus haziness, by far the most obvious manifestation of air pollution, is strongly dependent on particle size. Similarly, the health effect of particulate matter is largely dependent on particle size, since only particles of a certain size range penetrate into the lungs and are retained there. The particle size of interest in these areas is of the order of less than five or six micrometers. Such particles remain afloat virtually indefinitely and, while their contribution to the total weight of particulate matter is small, their number is very large.

By contrast, the emission of particulate matter is determined on a weight basis, whether by sampling or by material balance consideration. Thus the small number of relatively large particles accounts for most of the mass of particulate emission. Since particles in excess of 10 μm settle out rather rapidly, these particles do not contribute much to the ambient concentration of particulates, nor to their health and visibility effects.

---

(4) Air Quality Data - 1972 Annual Statistics, U. S. Environmental Protection Agency Office of Air Quality Planning & Standards, EPA-450/2-74-001.

Thus, a really useful inventory of particulate emissions would have to specify not only the mass but also the size distribution of particulate emission as well as their chemical composition -- a difficult and expensive task which cannot be carried out on a routine monitoring basis.

The problem is further complicated by the processes which form particulates -- mainly droplets -- in the atmosphere. The formation of SO_3 leads directly (via reaction with water vapor) to the formation of a sulfuric acid mist and to the stabilization of fog; photochemical reactions result in the polymerization of initially gaseous hydrocarbons, resulting again in particulate droplets. These products are only indirectly related to emission inventories.

B.4 Hydrocarbons

In the air pollution literature, the term "hydrocarbons" is used loosely to designate gaseous organic compounds. There are two major categories of sources of hydrocarbons in urban atmospheres: incomplete combustion and evaporation. Incomplete combustion occurs primarily in internal combustion engines (automobiles). Evaporation results from the storage and handling of solvents, petroleum products, etc. Additionally, methane is a normal constituent of the atmosphere, the result of natural decomposition processes.

Hydrocarbons participate in photochemical reactions leading to "smog", but their reactivity varies widely. It is therefore important to determine not only the amount of hydrocarbons present, but also their composition. From a practical point of view, usually only gross classification is possible on a continuous inventory basis, such as methane and non-methane hydrocarbons. Further separation into reactive hydrocarbons (olefins, diolefins, aldehydes, alcohols, etc.) and stable ones (e.g., parafins) is possible but will require an extensive sampling program. Complete analyses of samples collected in bags by means of a gas chromotograph are scheduled for samples of ambient air at St. Louis.

B.5 Oxides of Nitrogen (NO_x)

Emission inventories of nitrogen oxides constitute a special problem since these compounds -- particularly nitric oxide (NO) -- are primarily formed by nitrogen fixation during combustion operations. Their formation during combustion is a complex function of the time-temperature relationships in the combustion chamber, the amount of excess air present, and even the chamber configurations. Any nitrogen compounds present in the fuel also contribute to the formation of nitrogen oxides. Because of this, the nitrogen oxide concentration in flue gases cannot be calculated from a theoretical basis but must be determined experimentally for, at least, each typical situation.

In addition to combustion sources, there are specific point sources emitting nitrogen oxides, usually NO_2, such as nitric acid plants. The NEDS inventory does not show any such sources in the > 100 tons/year category in the St. Louis area.

As mentioned previously, the importance of oxides of nitrogen and hydrocarbons as pollutants is primarily as participants in photochemical reactions where NO_2 acts as primary light absorber. These compounds will therefore be of importance to RAPS only if and when a study of photochemical reactions in the atmosphere is planned.

B.6 Heat Emissions

The large amounts of energy produced and consumed by a city eventually are converted into heat, resulting in a "heat island" which has an effect on atmospheric stability and thus affects modeling efforts. A heat emission inventory is required for a comprehensive understanding of this effect in much the same way as a pollutant emission inventory forms the basis for an understanding of the fate of the pollutants.

Point sources contribute significantly to the heat emission inventory, since a sizeable portion of the energy consumed is wasted as sensible heat of the stack gases. Even in highly efficient power plants, about 20 per cent of the energy consumed is wasted at the plant. In some industrial operations, such as blast furnaces, essentially all of the heat of combustion is released to the atmosphere at the plant.

Actually, in a self-contained area such as St. Louis, not only the waste heat turns up as heat emissions, but virtually all of the converted energy as well. Except for minor amounts of energy stored as chemical energy (e.g., in a primary aluminum plant) or radiated into space as visible light, all other forms of energy, whether electrical or mechanical, are converted into heat and released into the atmosphere, spread out over the inhabited area. Thus, as a first approximation, the total Btu content of the fuel used at St. Louis can be assumed to be released at either point or area sources. The amount of heat released by point sources can be calculated directly from fuel consumption and known conversion efficiencies of the power boilers; it can be verified by stack analysis and measurement of gas volume and temperature, from which the sensible heat above ambient can be calculated.

Since fuel consumption figures will be obtained in any case, a program to calculate heat emission from point sources will be initiated. Significant point sources, defined similar to pollution point sources, will be treated individually, All other sources will be assigned to grid squares, whose total emission can be estimated, given the daily total of heating or cooling degree days, average wind speed, the day of the week and month of the year. Point sources can be classified into industrial, commercial and residential sources; power generation will be treated separately.

C. Sensitivity Analysis

An important aspect of every inventory is its accuracy. While no inventory can be better than the numbers supplied by the data acquisition process, a statistical estimate of the overall quality and probable error would help place the uncertainties on a quantitative basis.

As a first approach to this problem, the National Air Data Branch of EPA commissioned a study which produced a Weighted Sensitivity Analysis Program. While this program does not supply any estimates of the absolute accuracy, it does help evaluate the maximum permissible error of any part of the inventory, given a maximum permissible error for the whole system. In doing so, it keeps the inventory at an equivalent level of accuracy and points out areas where accuracy has to be improved to provide a desired overall accuracy. In addition, it also provides an approach to establish confidence levels for the emission inventory.

The basic theoretical development proceeds as follows(5). The linear model:

$$Q^2\Theta^2 = \sum_{k=1}^{N} Q_k^2 \sigma_k^2$$

where Q = total amount of pollutant emitted
$100\,\Theta$ = percentage error associated with Q
Q_k = amount of pollutant emitted by subclass k
$100\,\sigma_k$ = percentage error associated with Q_k

is postulated as an appropriate model to analyze the propagation of errors through the emission inventory.

---

(5) See F. H. Ditto *et al*, Weighted Sensitivity Analysis of Emission Data, Fed. Syst. Div., IBM, EPA Contract #68-01-0398 (1973).

If each subclass contributes to the error an amount proportional to its relative physical contribution, it can be shown that

$$\sigma_k = \Theta \frac{\sqrt{Q}}{Q_k}$$

The analysis demonstrates that to obtain a predetermined level of precision for a source class, not all subclasses need to be measured with the same precision; the greater the ratio of $Q:Q_k$ becomes, the greater becomes the allowable value of σ_k. Conversely, Q_k approaches the value of Θ as the ratio approaches unity (Figure 2).

The authors also developed a method for predicting the confidence level for the inventory; that is, the probability that the actual overall error will not exceed Θ, using Chebyshev's theorem(6). The results for selected pairs of (α and 1-c) are shown in Table III, where $\alpha = 2\Theta$ and 1-c is the confidence level.

A two-step procedure thus is suggested. First, establish the overall allowable error Θ, either from user's (modeler's) requirement or as a trade-off between confidence level and acceptable error interval; secondly, compute the values of σ_k for the components of interest.

Applying these considerations to our case suggests that, in the absence of any definite information about the modeler's requirements for the accuracy of emission data, a fairly stringent set of conditions would be a confidence level of 95 per cent and an acceptance interval of 10 per cent (these conditions are probably stricter than the accuracy of the emission data). This would lead to a permissible maximum error Θ of 2.24%

Using the emission values in the latest NEDS inventory, as shown in Table IV, we can now calculate the allowable error for source classes of various sizes, such as 100 tons/year, 1000 tons/year, etc. For example, the allowable error for a 100 tons source of SO_2 would be

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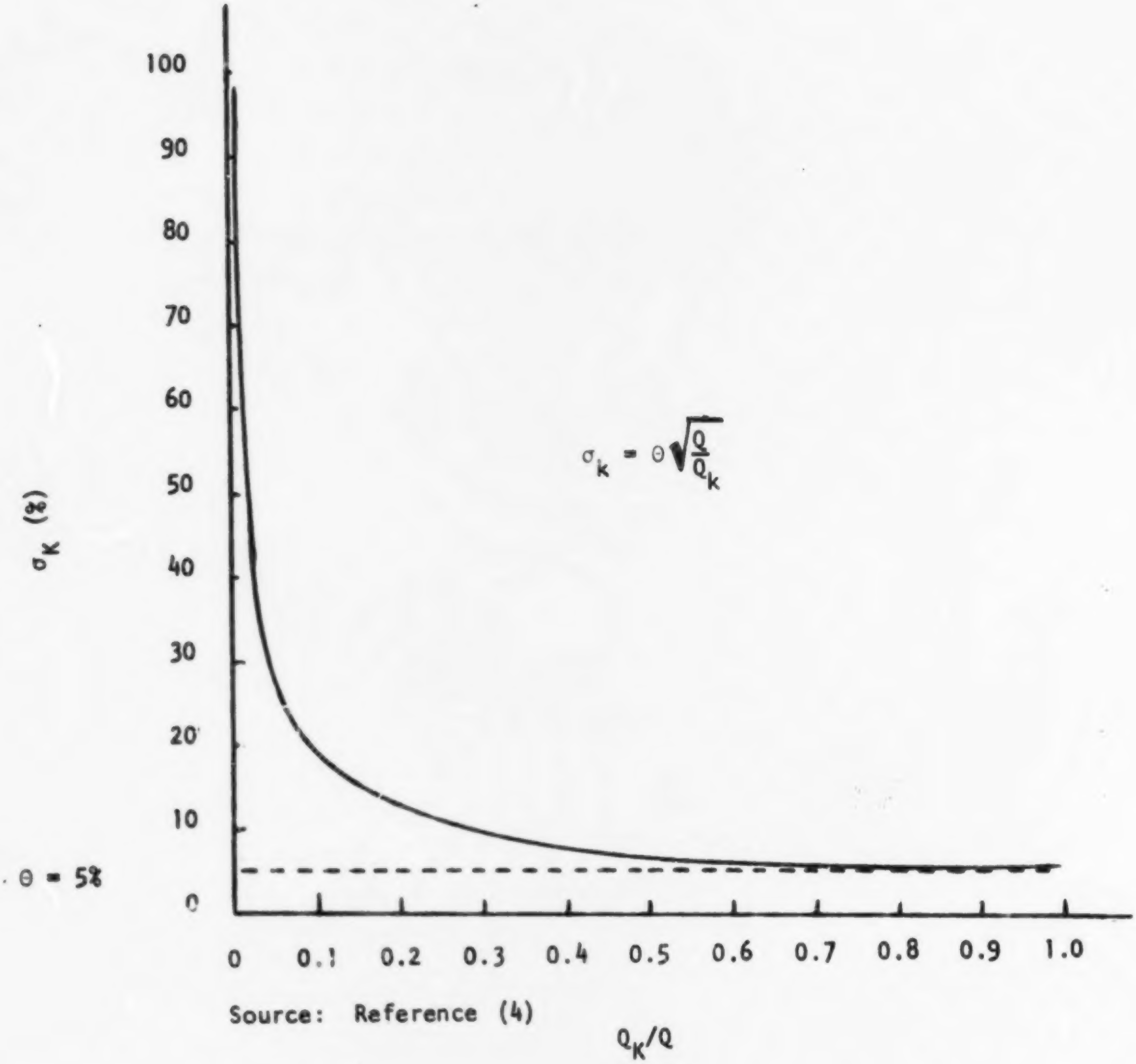
(6) Miller, I. and J. E. Freund, Probability and Statistics for Engineers Prentice-Hall, 1965.



Source: Reference (4)

RELATIONSHIP BETWEEN σ_K AND Q_K/Q

Figure 2

		Confidence Level		
	1-C α	90%	95%	99%
Acceptance Interval	5%	1.58%	1.12%	0.5%
	10%	3.16%	2.24%	1.0%
	20%	6.32%	4.47%	2.0%

TABLE III. VALUES OF Θ FOR SELECTED PAIRS (α, 1-C)

Source: Reference (4).

TABLE IV
POINT SOURCE EMISSION INVENTORY
NEDS, DECEMBER 1973

	STL Co.	STL City	St. Charles	Jefferson	Franklin	Wash.	St. Clair
SO_x	112,206	12,798	115,392	138,384	111,132	9	20,816
NO_x	34,979	2,647	60,086	214	28,492	5	4,069
CO	1,178	39,433	1,093	63	1,161	2	2,617
HC	9,255	15,965	328	3	303	1	4,024
Part.	12,129	6,527	321	835	1,244	900	23,623

	Randolph	Monroe	Madison	Clinton	Bond	Grand Total (Point Sources)
SO_x	473,599	--	202,630	270	--	1,187,296
NO_x	128,964	--	51,423	114	--	310,993
CO	2,993	--	2,787,726(?)	4	--	2,836,270
HC	901	--	47,694	2	--	78,476
Part.	6,399	359	271,338	277	--	323,952

NEDS, December 1973

$$\sigma_{100T} = \Theta \frac{\sqrt{Q}}{Q_{100T}}$$

$$= 2.24 \sqrt{\frac{1,187.296}{100}}$$

$$= 244\%$$

The data are tabulated in Table V.

The very large σ_k for SO_2, CO and even NO_x, even for the relatively stringent statistical conditions, suggests that there is probably no need to obtain measured hourly values for 100 tons/year sources of these pollutants, since in most instances NEDS can be relied upon to provide data of this accuracy. Thus the collection of hourly data can be limited to sources of 1000 ton/year and larger. As indicated in Table III (Section C), this will reduce the number of SO_2 sources to be measured to 62, the stationary CO sources to 13, and the NO_x sources to 26. The remaining sources can then be modeled as discussed in Section IV C3.

D. Size Distribution of Sources

The situation in St. Louis lends itself to a direct attack on the problem of direct measurement of emissions because of the relatively limited number of major point sources. In terms of SO_2, the current National Emission Data System (NEDS) inventory lists about 300 sources emitting over ten tons of SO_2 per year. Of these, only about 62 emit in excess of 1000 tons/year, an additional 120 over 100 tons/year. (Since sources emitting less than 100 ton/year are likely to contribute less than 10% of the amount specified by the National Air Quality Standards to ambient concentrations, they are usually lumped with area sources.) The 62 largest sources, representing 15 companies, are concentrated at 20 locations. Thus, the sheer physical magnitude of the problem of collecting hourly data for the major sources of pollution appears to be manageable within a reasonable budget.

The situation for other pollutants is somewhat similar. The data are summarized in Table VI.

Thus, if direct measurements of emission will be limited to sources emitting in excess of 1000 tons/year, we need to obtain data from 62 sources at 20

TABLE V

MAXIMUM ALLOWABLE ERROR σ_k FOR POINT SOURCES OF VARIOUS SIZE

ACCEPTANCE INTERVAL 10%, CONFIDENCE LEVEL 95%, Θ = 2.24%

POLLUTANT	TOTAL P.S. EMISSIONS, Q TONS/YR.*	ALLOWABLE ERROR σ_k FOR POINT SOURCE OF 100 T/Yr.	1000 T/Yr.	10,000 T/Yr.
SO_2	1,187,296	244%	77%	24%
CO	1,684,794	290%	92%	29%
NO_x	310,993	125%	40%	-
HC	78,474	63%	20%	-
PART	323,952	127%	40%	-

*Source: NEDS December 1973, except for CO, which is given in NEDS at 2,836,270, apparently in error.

TABLE VI

SOURCES OF POLLUTANTS IN THE ST. LOUIS AQCR

POLLUTANT	SO_2				CO				PARTICULATE				NO_x				HYDROCARBONS			
Tons/Year	$>10^3$	$>10^2$	>10	Total	$>10^3$	$>10^2$	>10	Total	$>10^3$	$>10^2$	>10	Total	$>10^3$	$>10^2$	>10	Total	$>10^3$	$>10^2$	>10	Total
No. of Sources	62	121	121	304	13	18	62	92	28	78	165	271	26	83	256	365	23	80	165	279
No. of Locations	20	15	17	52	9	8	13	30	12	25	29	66	10	13	36	59	10	22	24	56
No. of Companies	15	11	17	43	7	4	13	24	9	25	29	63	6	10	34	50	10	19	22	51

Source: National Emission Data System, Condensed Point Source Listings, SLIAQCR, December 1973.

locations for SO_2, 13 sources at 9 locations for CO, 28 sources at 12 locations for particulates, and so on. Many of these sources overlap, thus further reducing the data collection (but not the data recording) problems. For example, of the 26 major sources of NO_x, 21 are also major emitters of SO_2. The extent of the overlap is shown in Table VII, which lists all major sources of pollutants in matrix form.

E. Existing Inventory Data

Air pollution studies have been conducted in the St. Louis area for many years, and several emission inventories have been developed. In 1964, an "Interstate Air Pollution Study, Saint Louis-East Saint Louis Metropolitan Areas" was undertaken by the U.S. Public Health Service. Questionnaires were sent out to determine fuel use and combustible waste disposal practices in the area as well as manufacturing activities. A revised emission inventory, still based on 1963 data, was published in December 1966 as Phase II of the Interstate Study.

After the Metropolitan Saint Louis Interstate Air Quality Control Region had been established, the first comprehensive inventory was taken in 1968, to serve as a basis for the Implementation Planning Program (IPP). Since then, four more inventories have been compiled:

- IBM Emission Inventory-1970
- DAQED Emission Inventory-1971
- NATO Emission Inventory-1971
- NEDS Emission Inventory-1973

In addition, the following traffic and transportation inventories exist:

- Streets and highways
- Railways and vessels

The emission inventories in current use by the Missouri and Illinois regulatory agencies were recently (Summer 1973) acquired and transferred to the NEDS files.

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TABLE VII

SOURCES OF POLLUTANTS IN THE ST. LOUIS AQCR EMITTING IN EXCESS OF 1000 TONS/YEAR

Source Name	Point No.	Pollutant					Proposed Stack Sampling
		SO_2	CO	Particulates	NO_x	HC's	
Allied Chemicals	01	x					
Alpha Cement Co.	01			x			
Alton Box Co.	01	x			x		
	02	x					
	03	x					
Amoco	01	x	x	x		x	x
	02	x					
	03	x					x
	04	x			x		x
	05					x	
	06					x	
Anheuser-Busch Co.	01	x					
Anlin Corp.	01	x					x
Chrysler Corp.	01					x	
	02					x	
Clark Oil Co.	01	x	x	x		x	
	02					x	
	03					x	
	04					x	
Columbia Quarry	01			x			
	02			x			
East St. Louis Stone	01			x			
Ford Motor Co.	01					x	
	02					x	

TABLE VII CONTINUED

Source Name	Point No.	Pollutant					Proposed Stack Sampling
		SO_2	CO	Particulates	NO_x	HC's	
GMAC	01					x	
	02					x	
	03					x	
	04					x	
Granite City Steel	01		x	x			
	02		x	x			
	03		x	x			
	04		x	x			
	05		x	x			
Highland Electric Co.	01	x				x	
Illinois Power Co.	01	x	x		x		
	02	x	x	x	x		x
	03	x			x		
	04	x			x		
	05				x		
	06				x		
	07				x		
	08	x			x		
	09	x		x	x		x
	10	x		x	x		
	11	x		x	x		
Laclede Steel	01	x			x		
	02		x				
	03		x				

TABLE VII CONTINUED

Source Name	Point No.	Pollutant					Proposed Stack Sampling
		SO_2	CO	Particulates	NO_x	HC's	
Mississippi Lime Co.	01			x			
Mississippi Portland Cement	01				x		
Monsanto Chemical Co	01	x					
	02	x		x			x
	03	x					
	04	x		x			x
	05	x		x			
	06	x		x			x
	07	x		x			
	08		x				
	09		x			x	
Municipal Incinerator	01		x				
	02		x				
NL Titanium Div.	01	x					
	02	x					x
	03	x					
	04	x					
P P G Glass	01	x					
St. Joseph Lead Co.	01	x					x
	02	x					x
Shell Oil Co.	01	x					
	02	x					
	03	x					x
	04	x					
	05	x		x		x	x

TABLE VII CONTINUED

Source Name	Point No.	Pollutant					Proposed Stack Sampling
		SO_2	CO	Particulates	NO_x	HC's	
Shell Oil Co.	06	x		x		x	
	07	x					
	08	x					x
	09	x					
	10	x					
	11					x	
	12					x	
Socony	01					x	
Stolle Quarry	01			x			
	02			x			
Texaco	01					x	
Union Electric	01	x			x		
	02	x			x		
	03	x		x	x		
	04	x		x	x		
	05	x			x		
	06	x			x		
	07	x			x		
	08	x			x		
	09	x		x	x		x
	10	x		x	x		x
	11	x			x		
	12	x					
	13	x					
	14	x					

TABLE VII CONTINUED

Source Name	Point No.	Pollutant					Proposed Stack Sampling
		SO_2	CO	Particulates	NO_x	HC's	
Union Electric	15	x					
	16	x					
	17	x					
TOTALS	96	62	13	28	26	23	17

These inventories are described in detail in SRI Report "A Regional Air Pollution Study Preliminary Emission Inventory" (1974) EPA No. 68-02-1026.

Most of these inventories are only of historical interest. Current data are contained in the National Emission Data System (NEDS)[7] inventory, administered by the Federal EPA, and similar inventories kept by the Illinois EPA and the Missouri agencies.

The NEDS inventory contains information on annual emissions of the five "criteria" pollutants (particulates, SO_2, NO_x, hydrocarbons [HC] and CO) from stationary point and area sources, as well as a listing of selected industrial materials emitted by chemical process, food, agriculture, chemical and mineral products industries, petrochemical operations, wood processing, and incinerators.

From the point of view of the Regional Air Pollution Study, the NEDS inventory has two major uses: it contains emission data for those sources for which detailed data are unavailable, and it provides a basis for an analysis of the problem of obtaining measured data. It therefore can serve as an interim data base for the St. Louis study until the RAPS inventory becomes operational.

IV. Emission Data Acquisition

A series of sequential steps leads to the eventual acquisition and recording of point source inventory data for the RAPS inventory. The steps are:

- Survey
- Classification of Sources into Acquisition Groups
- Acquisition of Data by:
    1) Stack analyses
    2) Fuel consumption or process data
    3) Derivation from operational data
- Transformation of Data and Entry into Computer Bank

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(7) APTD-1135, "Guide for Compiling a Comprehensive Emission Inventory", March 1973.

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A. Survey

Classically, data for emission inventories are acquired by the use of questionnaires which are either mailed out or prepared by the interviewer or inspector on a one-time basis.

The requirements of the RAPS inventory for hourly measured data for a period of a year far exceed the normal reporting routine and require special arrangements with the management of the various facilities. Thus, personal contact with the appropriate corporate office by mail, phone and, ultimately, in person was considered essential to obtain the necessary cooperation. The request was made for access to data which would provide a basis for calculating hourly emissions (using OMB approved NEDS questionnaires as a starting point).

Such data could be

- stack concentration measurements
- fuel consumption records
- process data
- steam production records

These data, coupled with the necessary secondary information, such as stack gas volume, concentration of sulfur in fuel or in process materials, etc., will permit the calculation of the weight estimates of pollutant (e.g., SO_2) emitted per hour.

As a sample, appropriate officials of nine of the 15 companies emitting more than 1000 tons/year (shown in Table 2) were contacted and interviewed. These included Union Electric, Illinois Power, St. Joseph Lead, Alton Box Board, Laclede Steel, Monsanto Chemicals, Anheuser-Busch, Shell Oil Company, and Amoco Oil. These nine companies are responsible for over 90% of the total SO_2 emitted from point sources in the St. Louis area (based on NEDS data). All but two agreed to supply the necessary hourly data to RAPS; this includes the utility companies, who are emitting approximately half of all the SO_2 in the area. Thus, even if the percentage of cooperation of the smaller companies should drop off, it appears that measured data for at least 90% of the total emission of SO_2 will be available. The accuracy of these data is of the order of the finance accounting procedures used by the companies, which is higher than that of chemical analysis.

This type of a survey will be continued to include the remainder of the major sources. There are two levels at which the initial information has to be gathered:

1. Management level
2. Operational level

At the management level, an "agreement in principle" is required; usually operational personnel is present at these meetings since they will later on be involved. After an agreement is reached, the details of the data acquisition are worked out with operational personnel.

The following information is then secured from information gathered at the operating level:

1. Source Description: address, location (by UTM coordinates), type of operation (SIC and SCC Codes), etc. Most of this information is available in the NEDS printout but has to be verified (particularly location, which should be to ± 0.01 Km).
2. Needed Data: pollutant concentration in stack (rarely available), quantity and type of fuel burned, amount of steam produced, fuel analysis, process information (weight and analysis), etc. All of these data should be on an hourly basis; if they are not, the time interval should be noted, as well as time related variability.
3. Collection of Data: data collection will be arranged so as to minimize the effort required by the affected companies. A messenger circuit will be set up to pick up data once a week (or other agreed-on time interval). If required, the data may have to be reproduced; in some cases, mail arrangement will be worked out.

For point sources emitting less than 1000 tons/year, as well as those major sources where detailed data are not available, hourly emissions have to be derived by a model, as discussed further on under B3. For these sources, the following information is necessary.

1. Source description - as above.
2. Work schedule
3. Maximum process and space heating loads
4. Monthly and shift fuel weighting
5. Fuel analysis data

B. Classification of Sources into Acquisition Groups

The division of sources of pollutants into major (those emitting more than 1000 tons per year) and minor (emitting between 100 and 1000 tons/year), which is based on sensitivity analysis discussed above, produces two broad categories. Data from sources in Category 1, the major sources, will be collected on an hourly basis to the extent that they are available. Data from all other sources, that is the minor ones and those of the larger ones where detailed data are not available, will be derived by a modeling or algorithmic procedures.

In Group I are the utilities and the majority of sources emitting over 1000 tons/year of pollutant, as determined by the initial survey of sources. The data available from these sources permit a direct calculation of the weight of pollutants emitted any given hour.

Although sources in Group II contribute only a minor portion of the overall pollutant load, they may be of considerable significance locally. Under certain conditions it may become necessary to obtain measured emission data from some of these sources as a special project.

C. Acquisition of Data

C1. Stack Gas Measurements

The RAPS emission inventory should ideally contain direct statements of weight of pollutants emitted from each major source as a function of location for every hour. The most direct way to acquire this information would appear to be to monitor stack emissions.

In actuality, emissions (in terms of weight of pollutant) cannot be directly measured. Stack gas analyzers only provide a measure of the concentration of the pollutant, thus requiring another measurement -- stack gas volume -- before the weight of the emitted pollutant can be determined. Stack gas volume, in turn, is not measured directly, but rather is determined by measuring the gas velocity by traversing the cross-section of the stack. From the average velocity and the known dimension of the stack, the volume of the stack gases can be calculated. In addition, the molecular weight of the sampled gas has to be determined to obtain the mass flow rate. Thus, the seemingly direct and straight-forward approach to the determination of pollutant emissions by stack analysis actually consists of a number of measurements, manipulations and calculations, each of which contributes to the accuracy of the final figure.

In the case of SO_x, there is an alternative approach since all of the sulfur is contained in the fuel and is either emitted in the stack gases or remains in the residue (ash). The distribution of SO_2:SO_3 in stack gases has been found to be about 98-99:1. Therefore, the amount of SO_2 emitted can be determined quite accurately from fuel consumption and analysis figures, and the SO_2 inventory for RAPS will be obtained in this manner. With other pollutants, there is no choice, and stack sampling is the only way to obtain the desired information.

Stack sampling methods for compliance purposes have been standardized. EPA methods are described in CFR Title 40 (Protection of Environment) as an appendix to paragraph 60.85. The methods are:

Method 1: Sample and Velocity Traverses for Stationary Sources
Method 3: Gas Analyses for CO_2, Excess Air and Dry Molecular Weight
Method 4: Determination of Moisture in Stack Gases
Method 5: Determination of Particulate Emissions from Stationary Sources
Method 6: Determination of SO_2 Emissions from Stationary Sources
Method 7: Determination of NO_x Emissions from Stationary Sources
Method 8: Determination of Sulfuric Acid Mist and SO_2 from Stationary Sources.
Method 9: Visual Determination of Opacity of Emissions from Stationary Sources.

For the purposes of the Regional Air Pollution Study, continuous instrumental monitoring would seem to be preferable to the wet chemical analyses employed by the EPA methods. A mobile van containing instrumentation for the determination of SO_2, CO, HC, NO_x and possibly particulates is expected to be used in the later stages of the emission inventory.

Stack sampling is time consuming and expensive; for this reason, it should be used only to provide a primary calibration of emission factors which are used in conjunction with more readily accessible data, such as fuel consumption or processing rates. The most extensive collection of emission factors is contained in EPA's "Compilation of Air Pollutant Emission Factors" (AP-42) which is in almost universal use. Nevertheless, emission factors contained there are averages and vary widely in accuracy. They are rated for estimated accuracy on a scale ranging from "A" to "E", depending on the number and quality of field measurements on which they are based.

To insure the accuracy of the RAPS emission inventory, some stack testing has to be performed. Such testing should include at least one example in each SCC category; if budgetary constraints permit, a considerable number of important sources should be sampled individually (the SRI report (8) suggests a total of 65 stack tests). Tables VIII and IX show the distribution of the major sources by SCC categories.

By combining similar sources and matching categories with actual sources in the St. Louis AQCR, the following minimum schedule (Table X) was determined if at least one installation of each type is to be represented.

The total of 19 stack tests should really be considered as a "Phase 1" program, to be supplemented by further tests based on inspection and review of existing facilities.

As discussed above, SO_2 is the one pollutant for which adequate data can be obtained with only minimal stack testing, at least for those facilities which do not have any stack gas cleaning (scrubbing) equipment. At present, none of the boilers are equipped with such scrubbers; experimental work is being conducted with a "Catox" unit at the Wood River power plant.

Though fuel consumption and process data are potentially capable of providing quite accurate SO_2 emission figures, there is a hitch: sampling for sulfur analysis is not usually done adequately. Practices vary widely; some plants have continuous, automatic samplers, but these are located at the coal-pile end of the conveyor system. Since there are usually storage bins in the boiler-house itself, there is an 8 to 12 hour lag between the sample and the material burned. Most plants sample only intermittently -- once a shift, once a day, even once for each barge. Fortunately, the sulfur analysis of coal does seem to be fairly constant (about ± 10%). A statistical evaluation of the sampling procedures will be performed; when possible, the time lag will be incorporated in the calculations.

There is a way to get good coal samples, and that is to sample at the pulverizing mill, immediately ahead of the injection point into the furnace. If the sampling becomes a problem, it may be necessary to attempt sampling at that point.

Data for NO_x will have to be based almost wholly on stack testing. The EPA emission factors span a range of 3 to 55 pounds of NO_x per ton of coal,

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(8) A Regional Air Pollution Study (RAPS), Stanford Research Institute, 1974. Preliminary Emission Inventory

TABLE VIII

DISTRIBUTION OF LARGE SOURCES IN THE ST. LOUIS AQCR BY SCC CODES

External Combustion Boilers

SCC Code	Description	Number
1-01-002-01	External Combustion Boilers, Elect. Gen., Bitum. Coal, Pulv., wet > 100 x 10^6 Btu/hr.	7
02	Pulv., dry	14
03	Cyclone	4
08	Stoked	1
1-02-002-01	External Combustion Boilers, Industrial, Bitum. Coal, Pulv., wet > 100 x 10^6 Btu/hr.	1
02	Pulv., dry	3
04	Stoked	5
09	Stoked	5
004-01	Residual Oil	4
02	Residual Oil	1

TABLE IX

DISTRIBUTION OF LARGE SOURCES IN THE ST. LOUIS AQCR BY SCC CODES

Process Heaters & Processing Emissions

SCC Code	Description			Number
3-01-023-99	Industrial Process	Chemical Mfg.	H_2SO_4-Contact	2
999-99			Miscellaneous	2
-03-010-01			Lead Smelter	1
-04-004-03		Secondary Metal	Lead Smelter	1
-06-001-03		Petroleum Ind.	Process Heater,Oil	2
001-04			,Gas	4
002-01			Fluid Crackers	4
999-98			Miscellaneous	1

TABLE X

MINIMUM TEST SCHEDULE

A. POWER GENERATION

Equipment	Fuel	Firing Mode	Minimum No. of Tests	Suggested Location
Ext. Combust. Boiler	Bitum. Coal	Stoked	2	Monsanto
" " "	" "	Pulverized	2	Wood River-Labadie
" " "	" "	Cyclone	2	Sioux-Baldwin
" " "	Oil		1	Shell Oil
			7	

B. INDUSTRIAL SOURCES

Industry	Type	Minimum No. of Tests	Suggested Location
Chemical Industry	Sulfuric Acid	1	N.L.
	Miscellaneous	2	Monsanto-Anlin
Prim. & Sec. Metals	-	2	St. Joseph
Petroleum	Heaters	2	Shell-Amoco
	Crackers	2	Shell-Amoco
	Others	1	Amoco
		10	

40 to 105 pounds of NO_x per 10^3 gallons of oil.

C2. Fuel Consumption and Process Data

From the point of view of sampling methodology, there is no real difference between emission data based on fuel consumption and data based on processing of, as an example, a sulfide ore. In both cases, the hourly weight of consumed material determines the amount of gaseous discharge. Process data are more complex, though, since the amount of residual sulfur may be more significant and variable then in the case of a simple boiler operation. Of course, if a recovery operation is part of the process (e.g., a sulfuric acid plant), then stack sampling may become the more reliable source of data. The pattern of hourly variations may still have to be determined by process data unless continuous monitors are available.

An analysis of the NEDS inventory shows that the 62 point sources emitting in excess of 1000 tons of SO_2 per year fall into the following categories (Table XI).

TABLE XI

CLASSIFICATION OF SO_2 SOURCES

SCC Code	Category	Number
1-01	Boilers, Electric Generation	27
1-02	Boilers, Industrial	19
3-05	Petroleum Processing	11
3-xx	Other Industrial	5

Thus, almost 75% (46) of the 62 sources (including all of the large ones) are boilers; another 17% are concentrated in the petroleum industry.

Carbon monoxide, another combustion-related pollutant, has quite a different distribution (Table XII).

TABLE XII
CLASSIFICATION OF CO SOURCES

SCC Code	Category	Number
1-01	Boilers, Electric Generation	1
3-01	Chemical Process	2
-03,-04	Metal. Processing	6
06	Petroleum Processing	2
5-01	Incinerators	2

Here the largest sources are metal processing (blast furnaces, etc.), petroleum processing (cat. cracking) and certain chemical processes.

Even particulate emissions are largely related to boilers; almost half of the emission sources are boilers; another 25% comes from the mineral industry (quarries, cement plants, etc.). The breakdown is shown in Table XIII. The overlap of pollutants from different sources has been indicated in Table VII.

TABLE XIII
CLASSIFICATION OF SOURCES OF PARTICULATES

SCC Code	Category	Number
1-01	Boilers, Power	13
3-03	Metal Industry	4
3-05	Mineral Industries	7
3-06	Petroleum Processing	4

TABLE XIV

CLASSIFICATION OF NO_x SOURCES

SCC Code	Category	Number
1-01	Boilers, Elect. generation	22
1-02	Boilers, Industrial	2
3-05	Industrial - Cement	1
3-06	Industrial - Petroleum	1

TABLE XV

CLASSIFICATION OF HYDROCARBON SOURCES

SCC Code	Category	Number*	
1-01	Boilers, Elect. generation	(0)	9
2-01	Internal Comb., Turbine	(0)	2
3-01	Chem. Industry	(1)	4
3-03	Primary Metals - Cooking	(1)	2
3-06	Petroleum Industry - Processing	(4)	
4-03	- Evaporation	(11)	44
4-02	Surface Coating - Evaporation	(6)	19
5-01	Municip. Incinerator	(0)	2

*Bracketed numbers are sources in excess of 1000 tons/year; unbracketed are sources greater than 100 tons/year.

The significance of the high percentage of power boilers lies in the fact that data pertaining to boiler operations are usually well kept and more readily available than data about process operations. Since SO_2 emissions can be calculated readily from fuel consumption and analysis figures, and the emissions of other pollutants are closely related to fuel consumption and operating conditions, the acquisition of hourly fuel consumption data will go a long way toward the creation of an hourly emission inventory. For this reason, considerable emphasis will be placed on the acquisition of hourly fuel consumption (and related data), particularly in the early stages of the RAPS inventory effort.

The actual data obtainable cover a wide range of formats, from computer printouts of hourly fuel consumption to strip and circular charts, and even entries in log books. As an example, the logs of the Wood River Power Station of the Illinois Power Company for 29 April 1974 are attached. Table XVI is a computer printout, giving actual weight of coal used per hour, as well as information on boiler efficiency, BTU/lb. of coal etc. for Unit 5. On the other extreme, Tables XVII and XVIII show the oil and gas usage respectively of units 1, 2, and 3. Here data are available only per eight-hour shift and consist of single meter readings.

C3. Operating Data

This group includes all those point emission sources which are either minor (emitting less than 1000 tons/year) or for which no detailed hourly data are available. Here it is necessary to fall back on the annual data recorded in the NEDS inventory or the corresponding inventory of the local enforcement agency. An approach similar to Roberts(9) will be used to approximate the emission patterns by determining the relative amounts of fuel used for space heating and for process purposes and allocating each. Space heating requirements are distributed in accordance with degree-days (deviation of mean daily temperature from 65°F in degrees) while process loads are determined from appropriate month, day and shift factors. From these data, both the sulfur and heat emissions can be calculated.

Roberts assumes that when the temperature, T, is between -10 and 55°F, there is a linear relationship for the space-heating thermal load L^S. This is expressed as

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(9) For detailed description of such a system, see: Roberts, J. J., *et al.*, Chicago Air Pollution Systems Analysis Progress, Argonne National Lab., ANL/ES-CE007.

$$L^S = L^S_{MAX} \frac{[55 - T]}{65}, \quad (-10 < T < 55).$$

Then the total thermal load is

$$L = L^S + L^P,$$

where L^P, the process load, is determined from the appropriate month, day, and shift factors. The amount of load due to coal, L^C, and due to oil, L^O, is then determined, and the SO_2 emission due to each source is calculated as follows:

$$C\ (\text{tons/hr}) = \frac{L^C(\text{therms/hr}) \times 10^5(\text{Btu/therm})}{12000(\text{Btu/lb}) \times 2000(\text{lb/ton})}$$

$$SO_2^C(\text{lb/hr}) = C(\text{tons/hr}) \times 38 \times \%S^C;$$

$$O(\text{kgal/hr}) = \frac{L^O(\text{therms}) \times 10^5(\text{Btu/therm})}{18000(\text{Btu/lb}) \times 8000(\text{lb/kgal})}$$

$$SO_2^O(\text{lb/hr}) = O(\text{kgal/hr}) \times 157.0 \times \%S^O.$$

Thus, the total SO_2 emission is

$$SO_2 = SO_2^C + SO_2^O.$$

When the ambient temperature is such that a dual-fuel interruptible plant is probably receiving natural gas, the amount of SO_2 produced is correspondingly reduced.

To facilitate data storage according to a uniform and consistent format, each plant is assumed to have four stacks. For plants having less than four stacks, zeros are filled in for nonexistent stacks. The following parameters are associated with each stack:

1. SO_2 emission in pounds per hour
2. Heat emission in therms per hour.

These parameters are determined by weighting the total SO_2 and heat emissions for the plant by the percentage emitted from each stack. The heat emission, H, is assumed to be 15% of the thermal input.

V. Handling of Emission Data

As indicated in Section IV-C2, emission (or emission related) data will be provided in many different forms, ranging from computer printouts to strip or circular charts. The raw data will have to be read off the original records and tabulated in appropriate form before entry into the RAPS computer bank.

The format for the RAPS emission data storage has not yet been finalized. A data handling system (System 2000) will be used which is capable of storing data elements of variable length in repeating groups. The repeating groups define the structure for storing multiple sets of data values and link the hierarchical levels.

Data preparation forms will be designed to aid the data clerk in the structuring of the data and to make it easier to use the correct syntax. It will not be possible, however, to depend only on well-designed data preparation forms for data quality because the content as well as the form of the data must be verified.

Data verification can be carried out in part by the data management system, probably using a preliminary storage file which can be verified, proofread and corrected before the data manager decides that it is accurate enough to merge into the main file.

A detailed instruction sheet has to be prepared for each data sheet for the guidance of the data clerk. This sheet has to stipulate the units (if not indicated on the original record) and specify the manipulations, if any, which have to be performed to obtain hourly data which can be fed into the computerized RAPS inventory. In order to avoid human error as far as possible, only a minimum of handling will be carried out. For example, data will be recorded in whatever unit it is supplied and the units made part of the record. Transformation into standardized units can then be performed by the retrieval program to meet the specific needs of the user.

For most actual sources, the values stored will be consumption or other source data, rather than measured values of emission. The format will accommodate emission or consumption data. For those sources for which there are no direct emission data, emissions must be calculated using emission factors or models applied to the stored data. The emission inventory software system will be capable of assessing the consumption data element, refer to the appropriate code, look up the emission factor of model, and compute the emission values for each specified set of pollutants.

VI. RAPS Inventory Acquisition Schedule

The acquisition of the RAPS emission inventory comprises the following elements: 1) Survey and arrangement for data collection from measured sources; 2) Data acquisition and processing; 3) Acquisition of data from smaller sources; 4) Source testing.

The survey of sources from which hourly data should be obtained should be accomplished in about three months; this will include detailed arrangements which will spell out:

- which sources will be observed.
- what data will be forthcoming.
- the necessary factors to transform available data into mass emission units.
- the mechanism of data collection.

During the next three-month period, data will be collected and their transformation into machine readable data accomplished. Data collection will continue for at least a year, possibly longer.

Data from lesser sources will be collected concurrently, beginning with about month 6 or 7. Appropriate algorithms will be designed to provide hourly emission values.

A source testing program will be set up (under another task order) to provide verification of the emission factors and other assumptions used in the program. This should be an on-going effort, utilizing a mobile test unit and providing calibration data on 20 to 60 sources. The more sources are tested, the more reliable the inventory will become; this effort is limited mostly by budgetary considerations. A minimum program was outlined in Section C-1 (p. 27). This schedule is shown graphically in Figure 3.

GENERATION			GENERATORS						TURBINES								CONDENSER						BOILER															FUEL		PURITY		
GROSS MW	NET MW	L. P. GEN GROSS MW	GROSS MVARS	H. P. GEN. AMPS	H. P. GEN. H2 PSI	L. P. GEN. MVARS	L. P. GEN. AMPS	L. P. GEN. H2 PSI	MAIN STM FLOW—M#/HR	THROTTLE PRESS. PSI	MAIN STEAM TEMP. °F	COLD R. H. PRESS PSI	COLD R. H. TEMP °F	HOT R. H. TEMP °F	TURB. OIL FR. COOLER °F	TURB. H. R. BTU/KWH	BACK PRESSURE—"Hg	C. W. TEMP °F	C. W. (WEST) TEMP °F	C. W. (EAST) TEMP °F	COND. FL. TO D. A.—M#/HR	CONDENSATE TEMP °F	FEEDWATER FLOW—M#/HR	F. W. TO ECON TEMP °F	F. W. FR. ECON TEMP °F	ECON. GAS OUT TEMP °F	A H 5A GAS OUT TEMP °F	A H 5B GAS OUT TEMP °F	5A F D INLET TEMP °F	5B F D INLET TEMP °F	A H 5A AIR IN TEMP °F	A H 5B AIR IN TEMP °F	A H 5A AIR OUT TEMP °F	A H 5B AIR OUT TEMP °F	FLUE GAS O2 %	BOILER EFFICIENCY %-I.O.	BOILER EFFICIENCY %-H.L.	FUEL OIL FLOW GPM	COAL USE TONS/HR	SAT. STEAM MMHOS	COND. PUMP DISC MMHOS	PLANT H R—BTU/KWH
160.7	142.6	177	42	2446	26	80	2534	20	1014	1910	1016	242	680	1100	114	8592	4.0	60	35	35	927	79	951	377	534	556	270	274	66	604	143	141	508	503	0.0	87.0	91.7	0	75.2	2.3	1.7	10523
168.8	151.0	189	3	2375	25	- 1	2460	20	1046	1969	1031	242	682	1108	114	9073	4.0	60	35	35	946	79	948	357	533	559	271	276	66	604	142	141	505	504	0.0	87.6	91.6	0	76.0	2.4	1.7	10425
161.7	150.6	177	- 0	2360	25	- 4	2425	21	1012	1978	1030	243	680	1108	114	8942	4.0	62	36	38	935	84	928	398	533	559	278	275	65	604	142	139	505	505	0.0	86.5	91.6	0	75.9	2.4	1.6	10485
168.5	151.6	191	- 10	2371	25	- 9	2540	21	1035	1963	1027	243	679	1108	114	9131	4.0	63	35	34	953	78	949	398	534	561	278	275	65	604	142	140	507	507	0.0	88.2	91.6	0	75.9	2.5	1.9	10668
163.0	152.0	206	3	2451	25	- 8	2512	21	1123	1962	1027	243	678	1108	114	8962	4.0	60	35	34	937	78	933	398	534	557	271	274	65	604	142	140	506	507	0.0	86.4	91.6	0	76.5	2.5	1.9	10472
163.0	152.1	211	19	2350	25	6	2464	21	1037	1958	1031	242	681	1106	114	9109	4.0	60	34	34	950	78	946	397	536	560	271	275	64	604	142	140	507	508	0.0	86.8	91.7	0	77.8	2.6	1.8	10461
210.0	192.5	235	18	3090	25	3	3201	21	1347	1916	1043	305	695	1108	114	8743	4.0	60	38	37	1129	85	1212	440	557	625	279	285	63	604	135	133	544	544	0.0	83.7	91.5	0	99.8	2.5	1.6	10155
284.0	261.2	194	23	4635	25	10	4727	20	1925	1911	1020	408	706	1108	114	8460	4.0	59	40	39	1486	91	1707	458	579	669	284	291	63	604	127	123	576	579	0.0	88.2	91.3	0	130.7	2.3	1.5	9906
321.5	308.0	185	39	4639	25	18	4810	20	2121	1620	1044	473	708	1108	114	8721	4.0	59	39	39	1823	91	1840	459	517	671	287	285	65	604	121	115	562	564	0.0	89.1	91.1	0	142.3	2.0	1.4	9978
322.8	308.5	148	44	4811	25	21	4718	20	2120	1895	1034	468	704	1108	114	8712	4.0	59	39	39	1882	91	1843	458	576	668	287	296	66	674	123	121	582	583	0.0	90.1	91.0	0	141.8	1.9	1.3	10046
320.7	307.0	184	63	4803	25	32	4773	20	2120	[illegible]	1031	470	702	1108	114	8818	4.0	59	40	37	1881	91	1839	458	574	663	283	290	67	604	131	120	573	575	0.0	89.8	91.1	0	142.5	1.8	1.3	10102
321.0	307.5	188	57	4701	25	30	4763	20	2121	1891	1031	471	704	1108	114	8800	4.0	59	40	37	1877	91	1838	459	576	664	282	268	67	654	129	126	575	571	0.0	90.8	91.3	0	141.0	2.0	1.4	10017
320.7	307.5	119	59	4807	25	31	4757	20	2123	[illegible]	1034	470	704	1108	114	8814	4.0	59	40	37	1881	91	1834	459	575	664	284	291	67	604	128	125	574	576	0.0	90.3	91.2	0	141.7	1.9	1.5	10048
326.7	307.5	119	61	4728	25	31	4703	20	2122	1881	1034	461	700	1108	114	8792	4.0	57	40	34	1871	90	1820	458	576	664	283	290	68	604	129	126	574	578	0.0	89.9	91.2	0	141.8	1.9	1.4	10045
250.5	238.3	132	57	3675	25	30	3728	20	1130	1792	1042	366	700	1108	114	8522	4.0	59	37	36	1474	84	1422	434	561	617	275	260	67	664	135	133	543	546	0.0	88.8	91.4	0	113.9	2.1	1.6	10254
260.0	256.5	208	48	4299	25	26	4303	28	1764	1752	1028	425	692	1108	114	8882	4.0	59	39	38	1573	88	1527	449	569	645	230	287	69	684	132	130	561	562	0.0	89.3	91.5	0	121.1	2.0	1.5	10176
301.5	288.3	236	52	4633	25	27	4660	28	1761	1755	1043	450	701	1108	114	8783	4.0	60	40	38	1768	89	1714	455	574	658	281	268	68	604	125	122	570	572	0.6	89.5	91.1	0	134.0	2.0	1.5	10070
326.0	314.5	204	54	4934	25	28	4906	28	2149	1968	1026	460	697	1108	114	8706	4.0	59	40	39	1828	91	1843	460	581	672	284	290	67	684	127	124	579	580	0.0	90.0	91.2	0	142.7	2.0	1.4	9972
321.0	312.4	205	53	4843	25	25	4751	28	2174	1961	1028	454	694	1108	114	8705	4.0	59	40	39	1906	91	1882	457	578	672	284	291	68	684	127	124	578	580	0.0	90.5	91.2	0	143.3	1.7	1.4	10041
325.5	312.0	196	62	4874	25	30	4640	28	2147	1975	1039	454	707	1108	114	8721	4.0	59	40	39	1892	91	1872	461	581	676	284	291	67	604	127	124	580	582	0.0	90.8	91.2	0	142.4	1.9	1.4	9970
326.7	313.3	211	74	4849	25	27	4626	28	2131	1966	1041	456	711	1108	113	8729	4.0	59	40	39	1858	91	1823	461	584	682	286	238	67	684	125	122	584	586	0.0	90.2	91.1	0	142.9	1.9	1.4	9978
325.2	312.0	197	56	4685	25	29	4646	26	2121	1970	1029	454	700	1108	114	8623	4.0	59	40	39	1900	90	1606	458	581	674	284	291	67	684	125	123	581	584	0.0	89.3	91.1	0	142.1	1.8	1.4	9856
261.5	249.3	209	34	3946	25	19	3160	21	1730	1979	1023	360	677	1108	114	8897	4.0	57	36	35	1537	81	1310	420	552	608	272	275	67	664	139	136	537	538	0.0	94.3	91.4	0	111.7	1.8	1.6	10204
172.2	171.0	233	44	2537	25	25	2626	27	1171	2003	1011	242	681	1108	114	8983	4.0	[illegible]	34	34	1056	77	1066	378	537	552	277	266	66	674	153	132	511	508	0.2	88.0	91.7	0	82.8	2.1	1.8	11734

MEGAWATT HOURS		MILL	TONS	OTH TONS	HEAT INPUT & MISCELLANEOUS	
GEN	4538.1	5A	2	71803	COAL, MILLION BTU	62115
GEN	4355.1	5B	804	05443	OIL, MILLION BTU	0
66	1258.5	5C	651	26761	TOTAL, MILLION BTU	62115
	875.1	5D	708	83246	COAL HEAT VALUE, BTU/LB	11030
	5999.2	5E	485	39535	FUEL OIL USED GAL	0
L HO	0.0	TOT	2646		AVG C W IN TEMP, °F	60

TERMINAL DIFFERENCE °F			
HTR A	76.1		
HTR B	27.2		
HTR C	20.0		
HTR D	16.4		
HTR F1	15.0	HTR F2	0.7
HTR G1	12.1	HTR G2	11.7

HEATER DRAIN TERM DIFF °F			
HTR A	5.8		
HTR B	3.5		
HTR C	35.3		
HTR D	9.8		
HTR F1	2.1	HTR F2	1.3
HTR G1	2.5	HTR G2	13.3

BURNER TILT TIME		
%	A	B
+30 TO +15	15	122
+15 TO 0	428	265
0 TO -15	867	373
-15 TO -30	130	632
	MINUTES	

OPERATING DATA.		
HOURS	TURB.	BLR.
THIS MONTH	93	61
THIS YEAR	7085	3943
SINCE START	323235	3553
GROSS MWH THIS MO		19,06
AUX. MWH THIS MO		1043.1

ILLINOIS POWER COMPANY
WOOD RIVER POWER STA.
HOURLY AND DAILY LOG
UNIT 5

DATE 11 of 7

TABLE XVI.

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TABLE XVII

Form 201-66 (A)
Rev. 7-64

ILLINOIS POWER COMPANY
WOOD RIVER POWER STATION
BOILERS 1, 2, 3 DATA

APR 29 1974

DATE 3D

COAL SCALE	BOILER NO. 1 COAL SCALE RDG. A	B	C	BOILER NO. 2 COAL SCALE RDG. A	B	C	BOILER NO. 3 COAL SCALE RDG. A	B	C
Shift 12 MN - 8 AM									
1. Rdg. at 8 AM									
2. Rdg. at 12 MN									
3. Difference									
Shift 8 AM - 4 PM									
4. Rdg. at 4 PM									
5. Rdg. at 8 AM									
6. Difference									
Shift 4 PM - 12MN									
7. Rdg. at 12 MN									
8. Rdg. at 4 PM									
9. Difference									

10. Total Diff. Item 7 - Item 2									
11. Total Tons Item 10/5									

	GAS Meter Reading Start	Meter Reading End	FEEDWATER Meter Reading Start	Meter Reading End	STEAM Meter Reading Start	Meter Reading End	Meter Difference
Shift 12 MN - 8 AM							
No. 1 Boiler	340974	340613	642710	642808	532434	532502	
No. 2 Boiler	564941	564941	561863	561863	907408	907429	
No. 3 Boiler	858225	858586	002733	003074	003704	004055	
Shift 8 AM - 4 PM							
No. 1 Boiler	340613	341037	642808	643161	532502	532768	
No. 2 Boiler	564941	564954	561863	561863	907429	907451	
No. 3 Boiler	858586	858875	003074	3494	004055	4480	
Shift 4 PM - 12 MN							
No. 1 Boiler	341037	341458	643161	643523	532768	533045	
No. 2 Boiler	564954	565240	561863	562120	907451	907732	
No. 3 Boiler	858875	858934	3494	003679	4480	004688	

	HEATING STEAM 12 MN 8 AM	8 AM 4 PM	4 PM 12 MN	BLOWDOWN UNITS 1, 2, & 3 12 MN 8 AM	8 AM 4 PM	4 PM 12 MN
Meter Reading Start						
Meter Reading End						

TABLE XVIII.

(7)0.0/(17)25

1	42.5	08-24	H ✓
2	60.0	01-2	D ✓
3	0.0	01-24	H ✓

Form 271-147 (12/73)

Wood River STATION Daily Summary of Operations

St	Day	Month	Year	Start-Ups
	6	11	74	

	1	2	3	4	5
12:00	—	19		65	160
12:30	—	19		57	160
1:00	—	19		54	160
1:30		19		55	160
2:00	—	19		55	162
2:30	—	17		53	162
3:00	—	19		53	162
3:30	—	19		53	162
4:00	—	19		53	162
4:30	—	19		53	162
5:00		19		54	162
5:30	—	19		57	162
6:00		19		54	162
6:30		19		64	225
7:00		19		75	260
7:30	12	20		9[illegible]	300

Instantaneous Loads - MW

	1	2	3	4	5
8:00	22	24		100	340
8:30	54	57		102	340
9:00	41	44		102	390
9:30	40	41		102	390
10:00	40	41		102	390
10:30	41	44		102	390
11:00	41	44		102	390
11:30	40	40		102	390
12:00	34	24		102	300
12:30	30	30		102	390
1:00	15	16		102	390
1:30	14	16		102	390
2:00	17	16		82	340
2:30	19	16		87	310
3:00	14	16		87	270
3:30	15	16	21	86	270

	1	2	3	4	5
4:00	20	20	15	86	280
4:30	37	34		90	300
5:00	45	45		98	320
5:30	45	45		103	325
6:00	45	45		103	325
6:30	45	45		103	325
7:00	45	45		103	325
7:30	45	45		103	325
8:00	45	45		103	325
8:30	45	45		103	325
9:00	24	25		103	325
9:30	19	20		103	325
10:00	19	20		103	320
10:30	19	20		75	265
11:00	19	20		54	220
11:30	17	20		52	200
12:00	17	20		54	165

Fuel Usage

Coal 3110.60 Tons | Oil BBLS. 102453 Gals | Gas NONE MCF

	Boilers 1	Boilers 2	Boilers 3	Boilers 4	Boilers 5	Boilers 6	Boilers 7	Boilers 8	Turbines 1	Turbines 2	Turbines 3	Turbines 4	Turbines 5	Other Equipment Reducing Capability: Equipment	Time Off & On
Mark X if out of service at 12:01 AM		X	X						X		X				
Time On			730AM						713A						
Time Off											1130AM				
Time On											413P				
Time Off															

Remarks (*)

R.L. 402.
F-O 7'6
[illegible] · GAS

F.O. 7'5" to [illegible]
R.L. 406.7

RL 10'
FO 406.6

* Give brief explanation of any deviation from normal loading which is not apparent from the above listing of equipment out of service

Supervisor 12 M to 8 AM

RE
Supervisor 8 AM to 4 PM

J. Nagy
Supervisor 4 PM to 12 M

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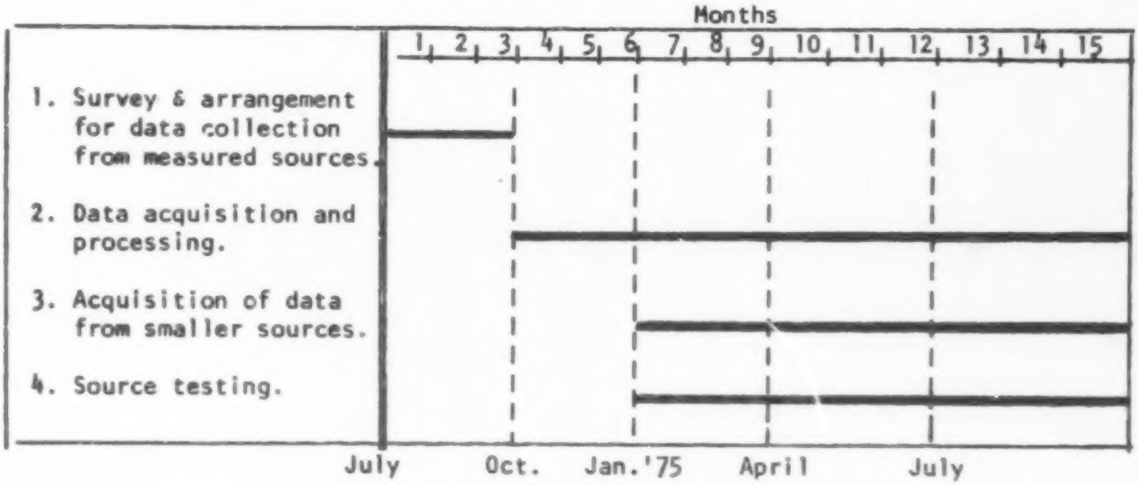

FIGURE 3. RAPS INVENTORY SCHEDULE

Acquisition of data (Step 2) will start about 1 October, 1974, using data obtained from Union Electric Company to check out the data entry system. By 1 November data from Illinois Power Co. will be added. Additional data, including all major sources (but limited to SO_2 only) will be included gradually. By 1 January 1975 the inventory of hourly SO_2 emissions from all major sources should be operational. Data from lesser sources will then be incorporated.

All incoming data will be entered on coding forms and visually checked for discrepancies. The tabulated data will then be transferred onto machine readable cards for delivery to NADB. Cards will be sent to NADB once a month.

VII. Summary and Conclusions

The history and purpose of the Regional Air Pollution Study in St. Louis was reviewed from the point of view of emissions of air pollutants and their inventories. Based on NEDS data on the size and distribution of the principal sources of air pollution and on a Weighted Sensitivity Analysis supplied by NADB, an emission inventory program methodology was designed to provide hourly data on criteria pollutants, with initial emphasis on sulfur dioxide. The criteria for choices were the estimated requirements of the most critical users of the data, the investigators working on dispersion model verification.

The methodology envisages a two-level approach: the measurement of hourly emissions or emission related data for the principal sources, defined as those emitting in excess of 1000 tons of pollutants per year, and a simulation of hourly emissions for smaller sources, based on yearly outputs and appropriate information on the consumption or production cycle.

The successful accomplishment of these goals should provide an emission inventory of a much higher accuracy than has heretofore been available.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.

2.

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE
Regional Air Pollution Study Point Source Methodology and Inventory

5. REPORT DATE
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7. AUTHOR(S)
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15. SUPPLEMENTARY NOTES

16. ABSTRACT

An emission inventory constitutes the starting point for any attempt to control emissions to the atmosphere. As long as such controls deal with average yearly concentrations, inventories giving total annual emissions of the various sources of pollutants are sufficient. The Regional Air Pollution Study has, however, as its first goal the validation of atmospheric dispersion models, which attempt to predict ambient pollutant concentrations on an hourly basis. Therefore, emission values derived from total annual emissions are largely inadequate, and the RAPS emission inventory was conceived to provide the needed time resolution and accuracy by measuring and recording hourly emissions (or parameters directly related to hourly emissions) and/or individualized hourly estimates derived for the principal sources of pollution. Thus, the emission inventory for the Regional Air Pollution Study (RAPS) at St. Louis is distinguished from existing emission inventories by two factors: its time and space resolution and its accuracy.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
SMSA Emission Inventory Point Sources Pollutants SCC AQCR		

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METHODOLOGY FOR INVENTORYING HYDROCARBONS

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NATIONAL EMISSION DATA BRANCH
DURHAM, NORTH CAROLINA

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CHAPTER I

INTRODUCTION

This document describes the methods for obtaining stationary source hydrocarbon emission inventory information, cataloguing the information consistent with the National Emission Data System (NEDS), and presenting the information for the evaluation of control strategies. The acquisition of statistical data and the procedure for surveying hydrocarbon stationary sources are described step-by-step. Both the manual approach and the use of computer data handling system are discussed for the analysis of data. Methodology development and application to the EPA Regional Air Pollution Study (RAPS) is also presented.

The definition of hydrocarbon emissions concerned in this report should be clarified. Hydrocarbons are normally thought of as compounds whose molecules consist of atoms of hydrogen and carbon only. Organic compounds include all compounds of carbon except the oxides of carbon, the carbides and the carbonates. Therefore, hydrocarbons are organic compounds. However, all organic compounds, including those which contain additional elements such as nitrogen, oxygen and chlorine, are also defined here as hydrocarbons. Throughout the report, the term hydrocarbon emissions will be synonymous with gaseous and the volatile portion of particulate organic compounds entering the atmosphere.

This report contains five additional chapters. Chapter II reviews the programs concerning the reduction of hydrocarbon emissions. Chapter III describes the methods for collecting information of the study area. Chapter IV delineates the procedure for selecting and surveying the hydrocarbon stationary sources. Chapter V discusses both the manual and computer assisted methods for compiling and presenting the data. And Chapter VI specifically addresses the utilization of this methodology to the Regional Air Pollution Study Program.

CHAPTER II

REVIEW OF HYDROCARBON PROGRAMS

Since the signing of the Clean Air Act and its amendments of 1970, many programs have been and are being conducted in the area of pollution related to hydrocarbon emissions. A review of the programs dealing with air quality standards, existing and evolving regulations, and the present emissions inventory systems, will lead to an adequate definition of the type of inventory information needed and the methods for collecting this information.

AIR QUALITY STANDARDS

EPA has promulgated two air quality control standards directly or indirectly concerned with hydrocarbons. The photochemical oxidant (or ozone) standard states that the hourly average concentration shall not exceed 0.08 ppm and the non-methane hydrocarbon standard states that the 6 to 9 a.m. average should not exceed 0.24 ppm (measured as "carbon").[1] The non-methane hydrocarbon standard was designed solely to meet the oxidant standard. The document on Air Quality Criteria for Hydrocarbons (AP-64)[2] clearly concludes that "our present state of knowledge does not demonstrate any direct health effects of the gaseous hydrocarbon in the ambient air on populations, although many of the effects attributed to photochemical smog are indirectly related to ambient levels of these hydrocarbons."

Research programs have developed methods for assessing the reactivity of various organic compounds present in auto exhaust and recently in the solvent and surface coating industries. The reactivities of the compounds vary and classifications have been made according to classes of compounds[3] or for specific compounds as in Table 1. However, "without additional information on the composition of the total hydrocarbon mixture and variability, it is difficult to appraise the relationships in the atmosphere between total hydrocarbon or non-methane hydrocarbon concentrations and photochemical effects."[2] Methane, a photochemically inactive hydrocarbon usually comprises more than half of total atmospheric hydrocarbon. An attempt to correlate photochemical products with non-methane hydrocarbons/total hydrocarbons has been made for several cities.[4] This has resulted in the development of the Appendix J curve, Figure 1, of the Federal Register (August,1971), which is used in the implementation plans to determine the percent reduction required in total hydrocarbon emissions in order to achieve the photochemical oxidant standard. One should note this curve was formed using the upper limit oxidant-nonmethane hydrocarbon points of various mixtures in certain cities over a certain period. It does not reflect the actual relationship of atmospheric hydrocarbons to photochemical air pollution levels over any study area. The application is supposed to assure that more than an adequate reduction is achieved.

STATUS OF NEDS FOR INVENTORYING HYDROCARBONS

Total hydrocarbons is one of the five criteria pollutants catalogued according to point and area source categories. Point and area sources definitions, along with the procedure for coding the computer input forms, are found in the "Guide for Compiling a Comprehensive Emissions Inventory" - APTD 1135.[5] It should be added that a source could be included as a point source if it can be controlled individually by a specific regulation. For example, the hydrocarbon regulation in Los Angeles, Rule 66, specifies "a person shall not discharge into the atmosphere more than 40 pounds of organic materials in any one day (~ 5 tons per year) from any article, machine, equipment ..."[6] It

Table 1. COMPOSITE REACTIVITY INDEX VALUES FOR SELECTED HYDROCARBONS[3]

Compound	Composite Reactivity Inc. (0 to 10 scale)
2-Butene, 2, 3-dimethyl	10
2-Pentene, 2, 3-dimethyl	9
2-Butene, trans-	8
2-Butene, cis-	8
1-Butene, 2-methyl-	8
1-Butene, 3-methyl-	8
2-Butene, 2-methyl-	8
2-Hexene, cis-	8
2-Hexene, trans-	8
3-Hexene, cis-	8
3-Hexene, trans-	8
2-Pentene	8
2-Pentene, cis-	8
2-Pentene, trans-	8
2-Pentene, 4-methyl-	8
1-Butene	7
1-Hexene	7
Formaldehyde	7
Isobutylene	7
1-Pentene	7
1-Pentene, 2-methyl-	7
1-Pentene, 4-methyl-	7
Propylene	7
Propylene Oxide	7
Styrene	7
Vinyl acetate, monomer	7
Vinyl chloride, monomer	7
O-Xylene	7
m-Xylene	7
p-Xylene	7
Benzene, 1, 2, 4-trimethyl-	6
Benzene, 1, 3, 5-trimethyl-	6
1,3-Butadiene	6
Butane, 2-methyl-	6
Cumene	6
Cyclopentane	6
Isobutyl methyl ketone	6
Propadiene	6
Toluene	6
Toluene, diisocyanate	6
Toluene, m-ethyl-	6

Table 1 (continued). COMPOSITE REACTIVITY INDEX VALUES FOR SELECTED HYDROCARBONS[3]

Compound	Composite Reactivity Inc. (0 to 10 scale)
Toluene, p-ethyl-	6
Trichloroethylene	6
Ethylene	5
Ethyl benzene	4
Cyclohexane	3
Cyclohexanone	3
Cyclopentane	3
Cyclomethyl	3
Ethyl methyl ketone	3
Hexanol, 2-ethyl	3
Isopropyl alcohol	3
Methyl alcohol	3
n-Butyl alcohol	3
Acetone	2
Butyl acetates, mixed	2
Ethyl acetate	2
Ethyl alcohol	2
Benzene	1
Butane, 2, 2-dimethyl	1
Butane, 2, 3-dimethyl	1
Hexane	1
Hexane, 2-methyl-	1
Hexane, 3-methyl-	1
Pentane, 2, 3-dimethyl-	1
Pentane, 2,4-dimethyl-	1
Pentane, 2,-methyl-	1
Pentane, 3,-methyl-	1
Pentane, 2, 2, 4-trimethyl-	1
Acetylene	0
Butane	0
Cellulose acetate	0
Diethylene glycol	0
Ethane	0
Ethylene dichloride	0
Isobutane	0
Isopentane	0
Methane	0
Methane, trichlorofluoro	0
Methyl chloride	0
Methylene chloride	0
Peptane	0
Propane	0
Perchloroethylene	0

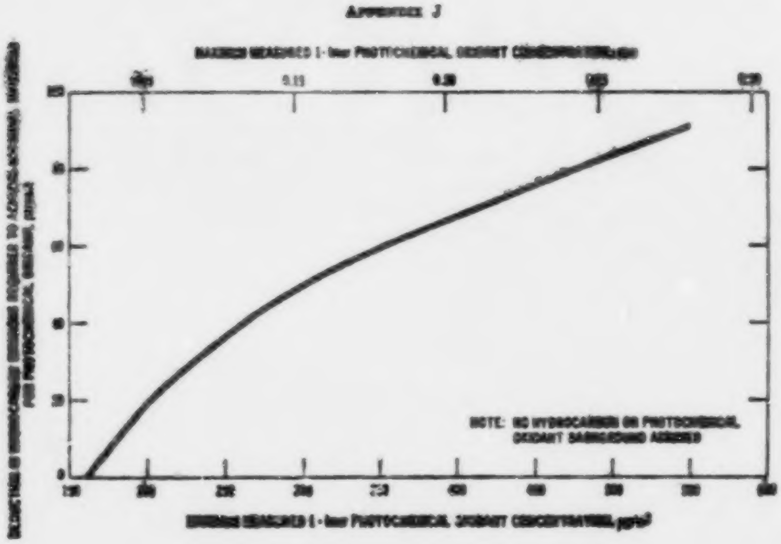

Figure 1. Required hydrocarbon emission control as a function of photochemical oxidant concentration. (Reference: Air Quality Criteria for Nitrogen Oxides, AP-84, Environmental Protection Agency, Washington, D.C., January 1971)

may be reasonable to choose 5 tons/year as a cut-off between point and area sources. The decision is an arbitrary one which also depends on the ease and cost of control and the extent of the photochemical problem.

Table 2 contains a summary of the 1970 nationwide hydrocarbon emissions, by source category.[7] Transportation was the largest hydrocarbon source, emitting 13.2 million tons (48.4 percent of the total) in 1970. The other major sources are, evaporative losses of gasoline and solvents, and industrial process losses. Combined, these sources contributed 9.6 million tons (35.5 percent of the total), in 1970.

Another estimate[3] of total hydrocarbon emissions is shown in Table 3. This summary presents emissions from stationary source categories which are generally higher than comparable estimates in Table 2 due to variations in methodology and data sources. The table also provides estimates of "high reactivity" emissions. "High reactivity" emissions are defined on the basis of photochemical reactivity or smog contribution as determined by simulative laboratory studies and represents that portion of emissions from the various source categories with a composite reactivity index of six or greater (see Table 1). High reactivity does not necessarily correlate with biological response.

Unlike the carbon monoxide and sulfur dioxide, which are specific compounds, the total hydrocarbon emissions consist of numerous types of organic compounds of varying toxicity and photochemical reactivity. These organic compounds may be emitted as a single compound or in combinations with certain others. The types and combinations of these compounds clearly depend on the process and item/product being manufactured or serviced. For some process categories, such as dry cleaning and degreasing, where operations are similar and standardized, the type of pollutant (as a compound) in many cases can be presently specified in the NEDS system via the Standard Classification Code (SCC). For some other categories such as chemical manufacturing and surface coating, the pollutant type information is not specified because the

Table 2. NATIONWIDE ESTIMATES OF HYDROCARBON EMISSIONS, 1970[7]

Source category P - Point sources A - Area sources	Emissions, 10^6 tons/year	Percent of total
Transportation (A)	13.2	48.4
Motor vehicles	12.0	44.0
Gasoline	11.9	43.6
Diesel	0.1	0.4
Aircraft	0.4	1.5
Railroads	0.2	0.7
Vessels	0.6	2.2
Nonhighway use of motor fuels (A)	2.0	7.3
Fuel combustion in stationary sources (P, A)	0.3	1.1
Coal	0.2	0.7
Fuel oil	0.1	0.4
Natural gas	0.0	—
Wood, LPG and kerosene	0.0	—
Industrial process losses (P, A)	5.5	20.1
Solid waste disposal (P, A)	1.5	5.5
Agricultural burning (A)	0.3	1.1
Miscellaneous (P, A)	4.5	16.5
Forest fires[a]	0.2	0.7
Structural fires	0.1	0.4
Coal refuse burning	0.1	0.4
Gasoline and solvent evaporation	4.1	15.0
Total	27.3	

[a] Includes prescribed burning.

7

Table 3. "BEST ESTIMATE" REACTIVITY RANKING OF MAJOR EMISSION SOURCES[3]

Source category	Total hydrocarbon emissions (10^6 tons/year)	"High reactivity" emissions (10^6 tons/year)
Solvent Evaporation	7.1	1.9
Solid Waste Combustion (urban, domestic, commercial, and industrial)	4.5	1.4
Agricultural Waste Combustion	4.2	1.1
Petroleum Products Storage and Marketing	2.3	1.0
Petroleum Production and Refining	1.9	0.2
Chemical Process Industry	1.4	negligible
Other Industrial Processes	~ 1.0	negligible
Fuel Combustion	0.4	negligible
Coal Refuse Burning	0.2	not estimated
Forest Wildfires	2.4 - 3.0	not estimated
Totals	25.4 - 26.0	5.6

SCC process codes have not been developed, or the pollutant is just categorized as solvent, paint solvent, lacquer solvent, etc. Solvents in mixtures vary but general classes could be outlined and SCC's defined. Still, for other categories such as area sources, where no SCC listing exists, only the material being stored, consumed or combusted is known. Emission factors are applied to these area source categories to calculate the total hydrocarbon emissions. If it is ever needed, the types, amount and variability from each area source category could be determined. For example, the marketing of gasoline certainly emits most of the compounds found in gasoline and the more volatile in larger quantities. Also, combustion of certain fuels usually produce various types of organic compounds within a limited concentration range.

REGULATIONS FOR THE CONTROL OF HYDROCARBON

A critical review of the existing and proposed regulations for the control of hydrocarbon emissions from stationary sources has recently appeared in the Journal of Air Pollution Control.[8] In summary, the various state and local agencies having a photochemical oxidant problem, have adopted some variation of the Los Angeles Rule 66.

Recently the National Paint and Coatings Association (NPC) has recommended modifications of Rule 66 for the control of Organic Solvents. These are proposed for use as new Federal Guidelines. These regulations or some slight modifications of them might eventually be adopted by the states or local agencies considering control of stationary hydrocarbon sources.[9]

It is evident that some of these regulations at times apply selective control to the particular categories or pollutant types. For example, below is a part of the regulation on organic solvent use:[9]

> A person shall not discharge into the atmosphere more than 40 pounds of organic materials in any one day, nor more than 8 pounds in any one hour, from any article, machine, equipment or other contrivance used under conditions other than described in section (a), (drying) for employing, or applying, any photochemically reactive solvent, as defined in section (k), or material containing such photochemically reactive solvent, unless said discharge has been reduced by at least 85 percent.
>
> For the purposes of this rule, organic solvents include diluents and thinners and are defined as organic materials which are liquids of standard conditions and which are used as dissolvers, viscosity reducers or cleaning agents, except that such materials which exhibit a boiling point higher than 220°F at 0.5 millimeter mercury absolute pressure or having an equivalent vapor pressure shall not be considered to be solvents unless exposed to temperatures exceeding 200°F.
>
> For the purposes of this rule, a photochemically reactive solvent is any solvent with an aggregate of more than 20 percent of its total volume composed of the chemical compounds classified below or which exceeds any of the following individual percentage composition limitations, referred to the total volume of solvent:
>
> 1. A combination of hydrocarbons, alcohols, aldehydes, esters, ethers or ketones having an olefinic type of unsaturation: 5 percent;
> 2. A combination of aromatic compounds with eight or more carbon atoms to the molecule except ethylbenzene: 8 percent;
> 3. A combination of ethylbenzene, ketones having branched hydrocarbon structures, trichloroethylene or toluene: 20 percent.

As specific and well defined as these regulations may be, the complex problem of evaluating the number and type of hydrocarbons emissions from a plant or class of industries still exists.

Under different circumstances, EPA has used different reactivity criteria in developing control strategies. The control regulations for automotive emissions require the control of all hydrocarbons. The regulations for gasoline marketing and distribution control all emissions, except that in some areas C_1 to C_3 paraffins, acetylene and benzene are exempted. For solvent usage, where control technology is not available, use of less reactive compounds has been permitted according to regulations similar to those given above.

CONCLUSION

From these earlier discussions, it is apparent that regulations have been and are being developed with the concept of photochemical reactivity. Up to now EPA has relied on the Appendix J relationship in the development of the implementation plans because of the unknown makeup and reactivity of the many organic components involved in the complicated photochemical reactions and forming oxidants. Since research is actively providing more information on these relationships, it appears that an accurate catalogue for inventorying hydrocarbons by type should be developed. The cataloguing of emissions should be consistent with the existing and eventual control strategies for meeting the oxidant standard. Toxicity effects should also be considered with the expectation that some organic compounds, i.e., vinyl chloride, will fall into the hazardous pollutant category.

CHAPTER III

DESCRIPTION OF REGION

To properly study a hydrocarbon emission problem for an area in question, it is necessary to have a complete description of the region. After the study area has been chosen, all necessary maps of the area should be obtained. City and county maps can usually be supplied by the State Department of Commerce and Development. Traffic count maps should be obtained from local and state highway departments and from metropolitan planning agencies. USGS maps should be used to identify the location (UTM's) of point sources.

It is very helpful prior to mailing a questionnaire, to have a general understanding of the types of major industries that exist in the study area. A list of manufacturing employees and/or number of establishments versus SIC (Standard Industrial Classification) can quickly reveal the major type of manufacturing industries in the area. This information can be obtained from the latest published Bureau of Census Data or the State Industrial Director. Table 4, constructed for the Boston AQCR, indicated SIC 38, 36, 31, 30 and 27 to be major industries. Petroleum bulk storage and distribution and dry cleaning establishments would also be included in any inventory because they are know emitters of hydrocarbons.

Statistical information that will be needed for the apportionment of hydrocarbon emissions to cities, towns, and counties are the following: population, number of establishments, number of manufacturing employees per SIC for cities, towns, counties, Standard Metropolitan Statistical

Table 4. MANUFACTURING EMPLOYEES IN REGION BY SIC CATEGORY, 1973

SIC category	Manufacturing employees[a]	~% of[b] U.S. Total
20 Food	21,900	1.6
22 Textile products	5,400	1.1
23 Apparel	17,300	
24 Lumber	2,400	0.6
25 Furniture	3,000	
26 Paper	11,600	(1.7)
27 Printing	25,000	2.1
28 Chemicals	9,000	0.9
29 Petroleum	1,000	(0.5)
30 Rubber	12,100	(2.3)
31 Leather	13,200	(3.9)
32 Stone, clay, etc.	3,000	(0.5)
33 Primary metals	3,400	0.3
34 Fabricated metal roducts	17,500	1.2
35 Machinery, non-electrical	34,000	1.7
36 Electrical machinery	52,000	2.7
37 Transportation equipment	16,600	0.8
38 Instruments	25,600	(6.2)
39 Miscellaneous manufacturing	6,900	(1.5)
Other	5,600	
	286,000	

[a] Primarily from September 1973 Massachusetts "Employment Newsletter"

[b] From ratio of 1973 Regional to 1970 National Bureau of Census Data, values in ( ) from 1967 Census Data

Areas (SMSA) and state. This information is usually available in Bureau of Census publications. Information about the labor force, population characteristics and general information for cities and towns can possibly be obtained from the local Development Council or the State Department of Labor. Often it is compiled in monographs for the respective city or town by state agencies.

Data concerning the amount of fuel consumed, transferred, stored, and produced for each state can be obtained from the "Mineral Industry Surveys" prepared by the U.S. Department of the Interior, Bureau of Mines.

Information about airport operations that are in the study area can be obtained from the Department of Transportation, Federal Aviation Administration.

Other ways of obtaining statistical information, which may not have been previously mentioned, can be found by referring to the reference sections in the "Guide for Compiling a Comprehensive Emission Inventory" (APTD 1135).

Metropolitan Boston Intrastate Air Quality Control Region, Figure 2, was a typical area chosen for a hydrocarbon emission study.[10] For this region the city replaced the county concept followed in NEDS.

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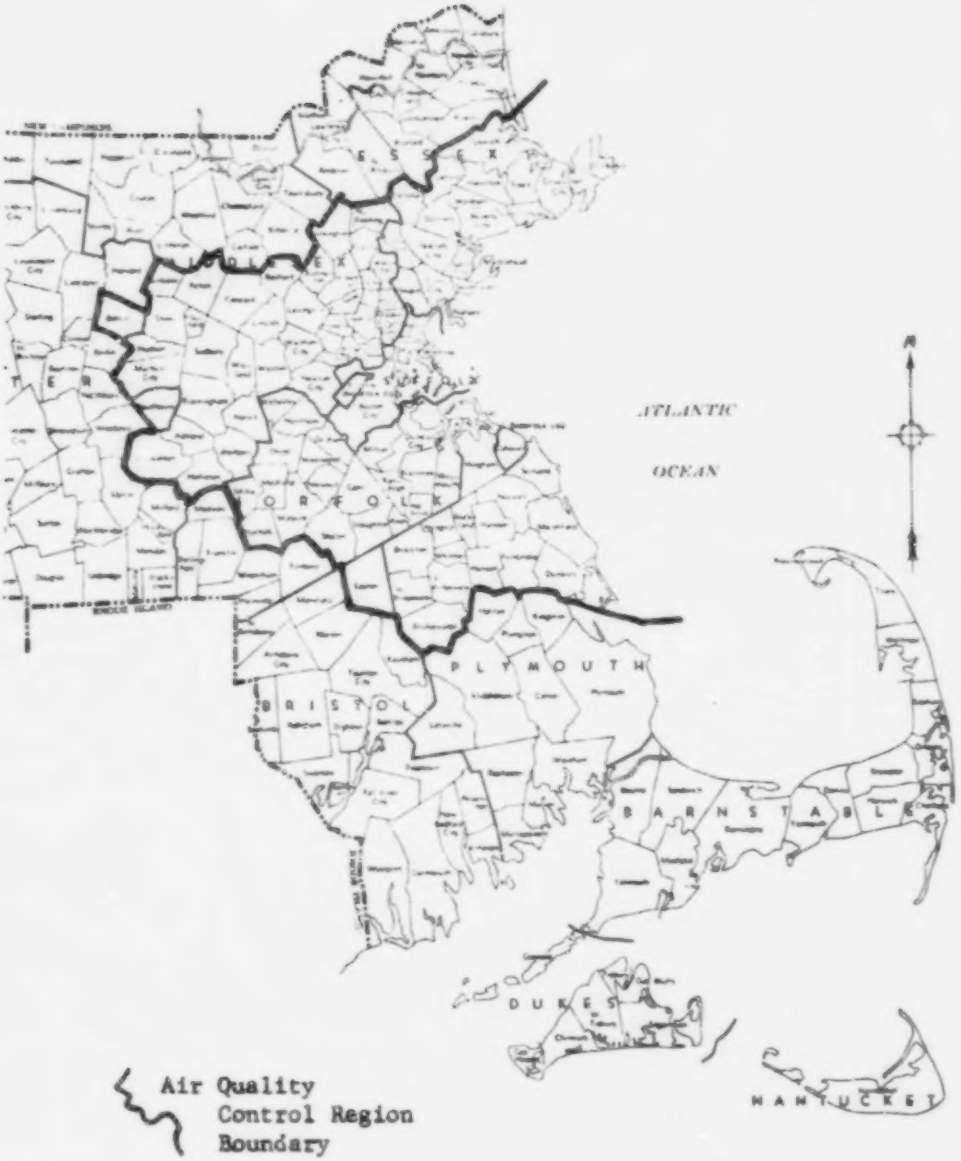

ESSEX
MIDDLESEX
NORFOLK
PLYMOUTH
BRISTOL
BARNSTABLE
DUKES
NANTUCKET
ATLANTIC
OCEAN
Air Quality
Control Region
Boundary

Figure 2. Metropolitan Boston Intrastate Air Quality Control Region

CHAPTER IV

HYDROCARBON STATIONARY SOURCE IDENTIFICATION

A primary purpose of a hydrocarbon inventory is to identify stationary point sources. This is best undertaken by means of a stationary source questionnaire. One byproduct of the questionnaire mailing is the gathering of information about small companies that do not emit hydrocarbons in sufficient quantity to qualify as point sources. Although these sources are small, they are numerous and may represent a substantial portion of the total hydrocarbons being emitted. The emissions from these area sources should be included in the NEDS area source file.

Hydrocarbon stationary sources can be broken down into the following categories: fuel combustion, solid waste, process and evaporative sources. Fuel combustion includes the burning of coal, oil, gas, and wood for residential, commercial, institutional, and industrial use. Solid waste stationary sources are on-site incineration, and open burning. Point and area source information for both fuel combustion and solid waste can be obtained from the existing NEDS file. It is felt that there is no real need to re-examine these point and area sources because of past emphases placed on them as emitters of criteria pollutants. The rest of this chapter discusses process and evaporative stationary sources.

PROCESS AND EVAPORATIVE SOURCES

Frequently hydrocarbon emissions from process and evaporative sources have not been carefully cataloged in the past. Therefore, it is necessary to re-examine the industries in the study area. A questionnaire designed specifically for particular classes of industries is effective in gathering the necessary process, emission and emission control information.

The questionnaire should be designed for three types of establishments: the manufacturing industries, the dry cleaners and the bulk petroleum products distributors.

Manufacturing Industries - (Questionnaire Design)

The operations that frequently emit hydrocarbons from the manufacturing industries are listed below.

1. Degreasing
2. Surface coating
    a. Fabric or rubberized
    b. Protective or decorative
    c. Printing
    d. Miscellaneous surface coating
3. Other manufacturing operations
    a. Process losses
    b. Bulk storage

The questionnaire for these manufacturing industries is shown in Appendix A, Table A-1. On the first page, general information is requested. Plant name and mailing address, plant address, person to contact, number of manufacturing employees, etc., are required for identification, scale up and completion of NEDS. To assist the respondent a guide (Page 1, Item G) is provided indicating the pages that should be completed for the operations performed at the plant. If the plant does not emit hydrocarbons, the respondent signs the form and returns it so he will not be recontacted.

Degreasing - In many industries, the fabricated product must be degreased before the application of surface finishes. The major solvents used in degreasing operations, Stoddard, 1,1,1-trichloroethane, perchloroethylene, methylene chloride and trichloroethylene are listed on the questionnaire. Space, of course, is also provided for other solvents. The respondent is also asked to identify the amount of each solvent purchased and returned for reprocessing. In order to assist in the determination of how much solvent is being sold in the area, the name of the solvent supplier is requested. The major solvent suppliers, if willing to disclose what may be considered as proprietary information, could provide information concerning total solvent usage within the area and help in the identification of major sources.

Surface Coating - The section concerning surface coating, should be handled carefully because solvents are added to the purchased coating. A distinction must be made between quantity of coating purchased and its solvent content, and the quantity of solvent added to the coating for dilution. The amount of solvent used for cleaning purposes is also requested. Since several solvents are often used, the type and percentage of the major solvents in the coating should be indicated on the questionnaire.

Manufacturing - The last operation in this major category is manufacturing. This part is a catch all, which includes such industries as asphalt roofing, plywood/particle board products and chemical manufacturing. Space is provided to describe the process or operation, to indicate the material being processed, to indicate the throughput at the source and to indicate the percentage and types of solvents being used and lost to the atmosphere.

In order to obtain the information required to fill out a NEDS form for a point source, one last page of information is needed. This part of the questionnaire concerns itself with control equipment and stack information. Every piece of equipment that has been mentioned in any previous page of the questionnaire should be given a unique source identification number. This number is used to match a piece of control equipment or a stack to the proper piece of operating equipment. Information that is needed includes the following:

- Process or operation having a stack and/or control equipment
- Control equipment specification
- Efficiency of the control equipment and its date of installation
- Stack information: height, diameter, gas temperature and velocity

The date of installation can be used to double check the reported efficiency of that equipment. If a piece of equipment is 50 years old and it is reported at 99 percent efficiency, a reasonable doubt exists as to the reported values.

Dry Cleaning - (Questionnaire Design)

Dry cleaning is the second category for which a questionnaire should be developed. It can be a separate questionnaire or incorporated into the manufacturing industries questionnaire as shown in Table A-1. Dry cleaners are requested to complete page 2 instead of pages -3- to -8- of the manufacturing industries questionnaire. General. stack, control and bulk storage information remains the same. The dry cleaning operation uses basically two types of solvents; perchloroethylene and some form of Stoddard solvent. The users of Stoddard solvent will, in almost all cases, use a type of process called a transfer machine. It is called a transfer process because after the clothes are washed they are transferred to a separate dryer. The physical process of moving the wet clothes necessitates that there will be a large evaporative loss. The second type of process used in dry cleaning is called a dry-to-dry machine and is also used by coin operated cleaning establishments. This process does not involve a transfer of clothes. The drying cycle is performed in the same machine as the washing cycle. The question of what type of process is being used should be included in order to check the usage figures of solvents. For the same amount of clothes cleaned and for the same type of solvent being used, the transfer process should use more solvent than the dry-to-dry process. As in the manufacturing questionnaire, the names of the suppliers of solvents are requested to assist in the determination of solvent usage in the area.

Bulk Storage of Petroleum Products (Questionnaire Design)

The last major category is bulk storage of gasoline and other petroleum and petrochemicals. In order to obtain information about storage tanks that a company may have on its premises, an abbreviated form of a bulk storage section is sent to all manufacturing industries (Section VII of Questionnaire). This shortened form asks for information concerning solvent type, capacity of the tank, annual throughput, and fill and control equipment.

The complete form, Table A-2, is sent to all major oil companies, petroleum and petrochemical distributors, utilities, and airports that have large bulk storage tanks. The questionnaire asks for information such as tank dimensions, paint on tank, average vapor space height, type of roof, vapor pressures of liquid, type of fill, etc. All necessary information is asked so that the emissions from the tank can be calculated based upon methods described in the Compilation of Air Pollution Factors, AP-42.[11] Emissions from product transfer are calculated by obtaining the type of fill (splash or submerged) and throughput at the loading racks.

DEVELOPMENT OF MAILING LIST

After a questionnaire has been developed for the specific area in question, a mailing list of potential hydrocarbon emission sources should be compiled. This list of companies can be obtained from many sources. Some examples are:

- State Industrial Directories
- State Department of Corporations and Taxation
- Dun and Bradstreet, Industrial Directory
- Yellow pages of telephone directories
- Thomas Register
- Trade and professional societies
- Existing NEDS and CDS for the state
- State Air Pollution Control Agency
- Local communities to obtain appraisal of industrial activity and listing of solvent storage facilities
- Manufacturers, suppliers and users of solvents and control equipment.

The selection of companies to be contacted is based on their SIC classification, with consideration given to their size and nature of their actual operations through preliminary contact with the firm, local municipalities or suppliers. Information from two previous studies shows significant use of hydrocarbons in the manufacturing industries (SIC 20 to 39), bulk storage and distribution of petroleum products (SIC 5171) and dry cleaning services (SIC 7216).

After the selection has been made of the industrial categories (SIC codes) to be surveyed by questionnaire, it is then necessary to determine if all the companies in the SIC will receive the questionnaires or whether only the most probable users of solvent based upon employee size will receive the questionnaire. Experience from past studies shows that it is helpful to make preliminary telephone calls to representative companies in an SIC. The information obtained can then be used to determine if all companies in this class would receive a questionnaire or whether for example, only companies with 50 employees or more should receive the questionnaire.

Table 5 presents guidelines that may be useful in the selection of companies based upon a previous Rhode Island study. The emission employee ratio is the ratio of tons of hydrocarbon emitted per employee as found from respondents. This figure can be used to determine the size of companies that should be inventoried. For example, if it is decided that all companies emitting more than 5 tons of hydrocarbon will be considered as point sources and the SIC emission employee ratio is 0.5, then all companies with 10 or more employees should be surveyed. It should be emphasized that this table is based on a small sample of all the U.S. industries and should be used with discretion until more hydrocarbon surveys are conducted.

The last two categories should be completely surveyed. A list of petroleum bulk stations and terminals can be obtained from the following sources:

1. State Air Pollution Control Agency
2. Department of Corporations and Taxation
3. New England Yellow Pages
4. Petroleum Industry Publications

A list of dry cleaning establishments can be obtained from either the Yellow Pages or from the Regional Dry Cleaning Trade Association.

The development of the mailing list involves classification of the companies that have been chosen to be surveyed into a logical order. But, before this is done it is necessary to minimize duplicate mailings. To do this all the mailing information about a company is keypunched on computer cards. This information is then sorted alphabetically by city or town. Visual spot checking will easily eliminate most of the duplicate names from the computer printout. However, even though extreme

Table 5. GUIDELINES TO DETERMINE WHAT COMPANIES WILL BE SURVEYED

SIC	Selection criteria	Emis./emp. ratio (tons/employee)
20 Food	Alcoholic beverages (2085)	-
21 Tobacco	Not surveyed	-
22 Textiles	Coatings (2295), Non-wovens (2297), Dyeing (2231)	0.89
23 Apparel	Not surveyed	-
24 Lumber & wood	Finished product (2435), (2492)	0.07
25 Furniture & fixtures	SIC: (2511), (2514), (2521) (2522), (2542)	0.08
26 Paper	Bags, box (2643), 2651), (2653), Coated papers (2641)	1.0
27 Printing	Newspaper publishing (2711) Comm. printing (2751), (2754)	0.5 0.20
28 Chemicals	Organic chemical mfg. (2821), (2823), 2861), Chemical coating (2851), Specialty chemicals (2842), Carbon black (2895)	0.32
29 Petroleum	All companies	0.11
30 Rubber, plastic	Footwear (3021), Plastics (3041), (3069)	0.16
31 Leather	Mfg. shoes (3149), Bags (3161), Personal goods (3172), Leather refinishing (3111)	-
32 Stone, clay, etc.	Glass products (3221)	0.03
33 Primary metal	Treating (3398), Tubing (3357)	0.10
34 Fab. metal	Screws (3451-2), Metal stampings (3469), Plating (3471), Tool mfg. (3423), (3429)	0.19
35 Machinery	Industrial machines	0.03
36 Elect. Machinery	Devices (3643), Semicond. (3674)	0.07
37 Transpt. equip.	Boats (3732), Truck bodies (3711), 13, 14, 15)	0.11
38 Instruments	Optical frames (3832) Precision instruments (3825)	0.04
39 Misc. Mfg.	Jewelry (3914-15), Toys (3944), Writing instr. (3951, 53)	0.07
5171 Bulk terminals	All surveyed	-
7216 Dry cleaning	All surveyed	-

caution is undertaken in developing the list, duplication of companies will still exist. This is due to the fact that some companies have more than one name (e.g., parent company, subsidiary, old name). This type of duplication generally will not be discovered until it is time to recontact those companies that did not initially respond.

A logical order in which to list and classify companies is first by SIC, then by city or county and finally alphabetically within the city or county. This order will increase the efficiency of all future work involved in data handling and in recording and analyzing response information.

COMPUTER LABELS AND WORK SHEET

A computer program can be very helpful in the mailing of the questionnaire, and in the production of a work sheet used for logging the returns. The computer program should produce duplicate mailing labels. The first label is attached to the general information page. This is done for identification of returned questionnaires and for name and mailing address correction. The second label is attached to the outside of the envelope. The label is shown below in Figure 3.

```
                                  XXXX
XXXX
 TRIAL NAME,
 STREET ZZ,
WOONSOCKET          R.I. 02895
```

Figure 3. Label contents

The SIC classification number is printed on the upper left and an assigned identification number on the upper right. The ID number is used to keep records of all correspondence with the company. In the middle of the label appears the company name, address, and zip code.

Figure 4 shows the work sheet listing of the companies in identification number order. It is used to record the dates questionnaires were mailed and returned, the telephone numbers, the telephone contact notes, and comments. The comment space can contain the type of source, process, emissions and number of manufacturing employees required for data analysis. The computer program listing for doing the above tasks is found in Appendix B.

MAILING OF QUESTIONNAIRE

There are certain procedures that should be followed to assure a good questionnaire response. Legal requirements should also be considered; for example, some state regulations may require that prior to the mailing of a questionnaire ample notice be given in local papers. A cover letter such as that shown in Figure 5 should accompany all questionnaires, this letter should state the purpose of the study, make reference to any proposed or applicable regulations, and request cooperation. General procedures and instructions for the previously designed questionnaire such as those shown in Figure 6 should also be provided. These instructions should request completion and return of the questionnaire by a specific date and specify the year for which the data is requested. The instructions also should explain that the questionnaire was designed for a wide variety of operations which involve solvent and organic chemical usage, and that some questions may not apply to a particular facility. A telephone number should be supplied in case a respondent has questions concerning the form.

The mailing of the questionnaire can be performed in two ways. The first method is by registered mail. Using this method the agency is assured that the questionnaire is received by the company. The percent response will probably be higher than if than if the letter was sent by conventional mail. However, there is still no guarantee that the company will return the form. It is felt that the slight increase in response does not justify the added expense of sending every company a registered letter.

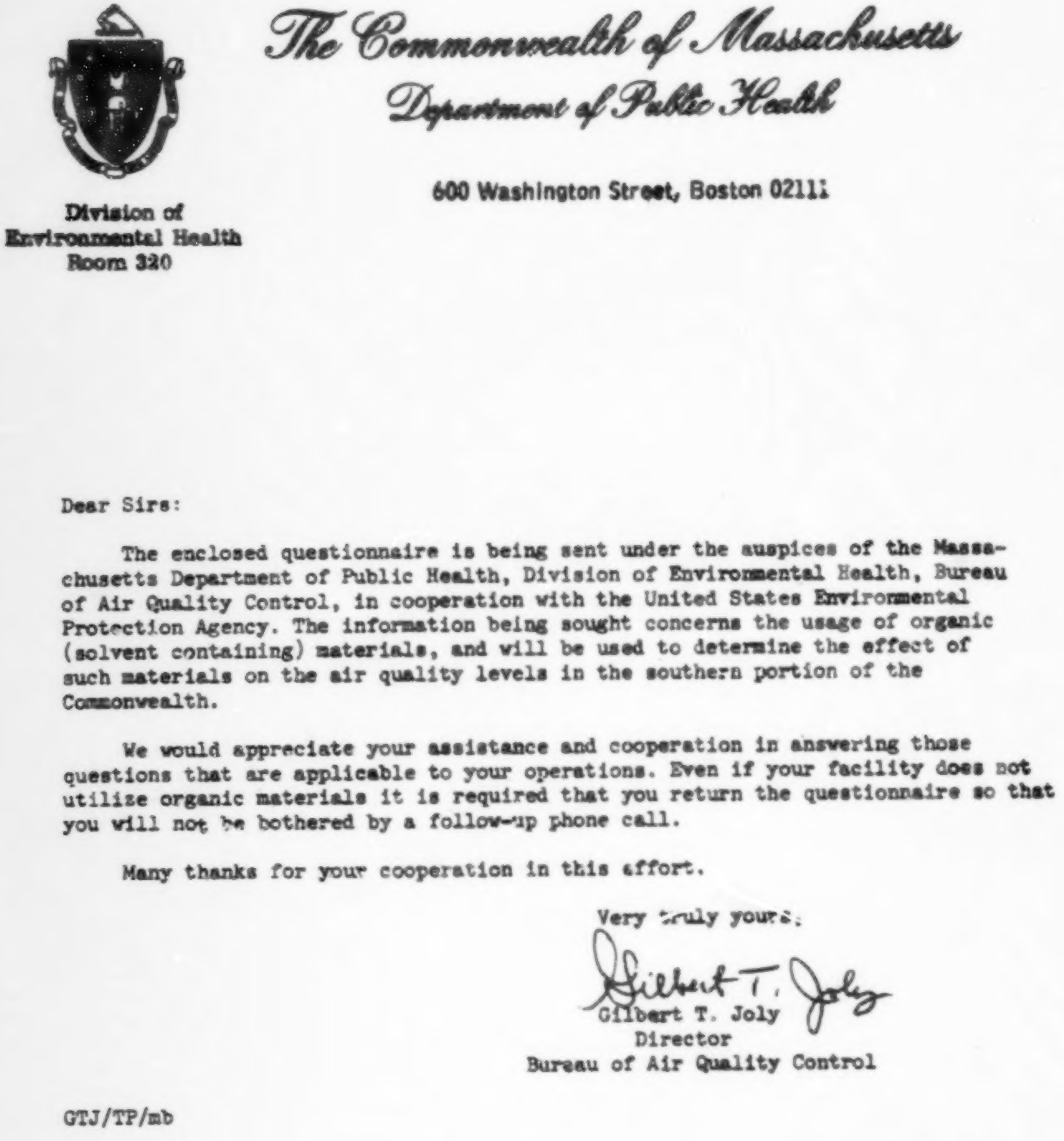
```
                                     TEL NO     DATE Q IN  TEL CONT   TEL CONT   TEL CONT    COMMENTS

------------------------------------+----------+----------+----------+----------+----------+------------
  XXXX                  XXXX        +          +          +          +          +          +
   TRIAL NAME,                      +          +          +          +          +          +
   STREET ZZ,                       +          +          +          +          +          +
  WOONSOCKET      R.I. 02895        +          +          +          +          +          +

------------------------------------+----------+----------+----------+----------+----------+------------
  XXXX                  XXXX        +          +          +          +          +          +
   TRIAL NAME,                      +          +          +          +          +          +
   STREET ZZ,                       +          +          +          +          +          +
  WOONSOCKET      R.I. 02895        +          +          +          +          +          +

------------------------------------+----------+----------+----------+----------+----------+------------
                                    +          +          +          +          +          +
                                    +          +          +          +          +          +
                                    +          +          +          +          +          +
                                    +          +          +          +          +          +
```

Figure 4. Work sheet contents



The Commonwealth of Massachusetts
Department of Public Health

600 Washington Street, Boston 02111

Division of
Environmental Health
Room 320

Dear Sirs:

The enclosed questionnaire is being sent under the auspices of the Massachusetts Department of Public Health, Division of Environmental Health, Bureau of Air Quality Control, in cooperation with the United States Environmental Protection Agency. The information being sought concerns the usage of organic (solvent containing) materials, and will be used to determine the effect of such materials on the air quality levels in the southern portion of the Commonwealth.

We would appreciate your assistance and cooperation in answering those questions that are applicable to your operations. Even if your facility does not utilize organic materials it is required that you return the questionnaire so that you will not be bothered by a follow-up phone call.

Many thanks for your cooperation in this effort.

Very truly yours,

Gilbert T. Joly

Gilbert T. Joly
Director
Bureau of Air Quality Control

GTJ/TP/mb

Figure 5. Cover letter

HYDROCARBON (SOLVENT) EMISSION STUDY
FOR STUDY AREA

The Division of Air Pollution Control, Department of Public Health requests your cooperation in providing the information asked for on the attached questionnaire concerning potential hydrocarbon emissions resulting from the operation of your facility. Hydrocarbons are gaseous organic compounds.

BEFORE FILLING OUT THE QUESTIONNAIRE PLEASE READ THE FOLLOWING INSTRUCTIONS:

- Everyone receiving this form should complete Section I (General Information) and all other sections pertaining to his firm and return the questionnaire in the stamped, addressed envelope.
- Please return the questionnaire on or before May 17, 1974. Your cooperation and expeditious completion of the inventory forms will be appreciated.
- Indicate any change in name and/or address in Section I.
- The information submitted should pertain to the calendar year of 1973.
- The questionnaire was designed for a wide variety of operations which involve extensive solvent usage. Accordingly, many questions may not apply to your facilities. Please complete only those sections that are applicable to your operations.
- If there is more than one plant location, please request additional copies or photocopy it for each facility.
- If the space provided is not adequate, feel free to either copy the form, use a separate sheet or request an additional copy.

Your cooperation in filling out this form is greatly appreciated. If you require additional forms or further information, please contact Mr. X or Mr. Y, Tel. No.: XXX-XXXX

*Division of Air Pollution Control
Street Address
City, State, Zip Code

Figure 5. General instructions for completing questionnaire

HYDROCARBON (SOLVENT) EMISSION STUDY
FOR STUDY AREA

The Division of Air Pollution Control, Department of Public Health requests your cooperation in providing the information asked for on the attached questionnaire concerning potential hydrocarbon emissions resulting from the operation of your facility. Hydrocarbons are gaseous organic compounds.

BEFORE FILLING OUT THE QUESTIONNAIRE
PLEASE READ THE FOLLOWING INSTRUCTIONS:

- Everyone receiving this form should complete Section I (General Information) and all other sections pertaining to his firm and return the questionnaire in the stamped, addressed envelope.
- Please return the questionnaire on or before May 17, 1974. Your cooperation and expeditious completion of the inventory forms will be appreciated.
- Indicate any change in name and/or address in Section I.
- The information submitted should pertain to the calendar year of 1973.
- The questionnaire was designed for a wide variety of operations which involve extensive solvent usage. Accordingly, many questions may not apply to your facilities. Please complete only those sections that are applicable to your operations.
- If there is more than one plant location, please request additional copies or photocopy it for each facility.
- If the space provided is not adequate, feel free to either copy the form, use a separate sheet or request an additional copy.

Your cooperation in filling out this form is greatly appreciated. If you require additional forms or further information, please contact Mr. X or Mr. Y, Tel. No.: XXX-XXXX

*Division of Air Pollution Control
Street Address
City, State, Zip Code

Figure 6. General instructions for completing questionnaire

The second method is by conventional first class mail. This method previously used in past studies has proved to be effective if, on the outside envelope, the following expression is clearly printed, "ATTENTION: PLANT MANAGER." This expression directs the envelope to the proper supervisory personnel and reduces the chances of the envelope being discarded. Included with the questionnaire should be a self-addressed stamped envelope. The public is more likely to return the questionnaire if the postage has already been prepaid.

One factor that should be considered before the mailing is whether or not to stagger the mailing over a time period. If a large number of questionnaires (1,000 or greater) are to be mailed, a staggering of the mailing should be considered. This allows for a more even flow of returns and eases the task of recording information contained in the returned questionnaires. If the mailing is spread out over extended periods of time the return date of the questionnaire should also be staggered accordingly. Companies should be given a reasonable amount of time to respond. For most companies, approximately 3 to 4 weeks is sufficient.

Generally, responses will start coming in within a few days after mailing. Many of the early returns will be from companies that do not use hydrocarbons in their facility. Also, some of the envelopes will be returned from the Post Office because either the establishment is out of business or because the company is no longer at that address. New addresses for companies that have moved can be obtained by either looking up their addresses in the telephone book or by contacting the Department of Corporations and Taxations.

LOGGING OF RETURNS AND FOLLOW UP

Emission calculation can be performed on the questionnaires as soon as they are returned. One of five classifications should be designated on the return:

- P - Hydrocarbon point source
- A - Hydrocarbon area source
- N - No hydrocarbon emission, non-source
- OOB - Out of business
- R - Recontact for reclassification

Emission from many sources within a company should be broken down into individual point sources. The smallest point source that should be considered within a company is one having at least 1 ton of emissions.

As the responses come in, changes should be made to correct any mistakes made in the company's name, address or SIC classifications. Information required for data compilation is recorded on the work sheets described in Chapter V.

RECONTACTING

Approximately 3 to 4 weeks after the questionnaires were initially mailed, recontacting should begin. This can be accomplished by either of two methods, telephone or letter. The advantages to recontacting by telephone are direct verbal communication, and lower costs when the calls are local. Direct communication quickly identifies any problem areas. Process information can also be obtained over the telephone. In an average 8-hour work day it is possible for one person to recontact approximately 30 to 40 companies. A good approach is to select the larger companies in SIC categories emitting significant amount of hydrocarbons. Certainly all the bulk storage establishments should be recontacted.

CHAPTER V

DATA COMPILATION

There are two approaches for compiling the data into summary tables that can be used to analyze hydrocarbon source emissions and study the effects of regulations. One approach is to process the information manually. The other is to use a computer data handling system. The selection of one approach over another depends on several factors. The computer approach is advantageous when the data base is large, a variety of tabular summaries have to be produced and the tasks are iterative. The computer approach also forces organization. Since the tasks are done systematically, this leads to accuracy and efficiency.

It has been noted that the methodology for inventorying hydrocarbons requires information on numerous organic compounds from a variety of processes Because of this complexity and the eventual need for many studies of this type to be done for different regions (states, AQCR) in the future, it is recommended that a computer data handling system be developed similar to that described in the paragraphs entitled "Computer Data Handling System," in this chapter. The manual approach, which has been used as the basis for the development of the computer data handling system, is described thoroughly in the section entitled "Manual Approach." It may be followed for small data bases or when more flexibility or variation from the computer system approach is desired.

MANUAL APPROACH

The data in the questionnaires and the information gathered on the return log sheet are used to do a survey coverage analysis and to prepare a point and area source listing work sheets by major emission categories. The extent of survey covarage and hydrocarbon emission information by by category is then used to estimate total stationary source hydrocarbon emissions. The information on point source work sheets is coded onto NEDS point source forms. Area sources estimates for each major manufacturing and evaporative category are calculated and then summed for entry by county into the evaporation field of the NEDS area source form.

Other hydrocarbon area source emissions for each county are calculated either by the NEDS area source computer program or manually as specified by the "Guide for Compiling a Comprehensive Emissions Inventory,"[5] APTD-1135 and "Compilation of Air Pollutant Emission Factors," AP-42.[11] Point source hydrocarbon emissions from fuel combustion and solid waste are also obtained from the NEDS point source printout.

Total hydrocarbon emissions can be summarized by source category for the region or each county as shown in Table 6. The Pi chart in Figure 7 is an excellent way to illustrate the percent contribution of each source category. A table similar to Table 7 is used to list the point sources. Finally, an analysis of each source category can detail the types of processes, types of hydrocarbon species emitted, and types of equipment presently in use or available for control.

Survey Coverage Analysis

The extent of survey coverage and the resulting emissions is demonstrated in Table 8. The latest census data on the number of companies and manufacturing employees by SIC presents a good accurate picture of what can fully be surveyed. The number of companies surveyed was based

Table 1. SUMMARY OF HYDROCARBON EMISSIONS FOR 1973 IN RHODE ISLAND

Source category	Point source		Area source emissions	Total emissions
	Number[a]	Emissions		
Dry cleaning	29	370	907	1,277
Degreasing	120	2,911	1,830	4,741
Surface coating	103	9,040	5,316	14,356
Fabric/rubber				(2,225)
Protective/decorative				(4,108)
Printing				(1,828)
Miscellaneous				(4,395)
Trade Paints				(1,800)
Manufacturing	9	721	74	795
Bulk petroleum products Storage	20	7,945	~ 0	7,945
Fuel combustion	50	293	958	1,251
Solid waste incineration	5	36	~ 0	36
Gasoline marketing	NA	NA	4,118	4,118
Aircraft	NA	NA	1,211	1,211
Railroads & vessels	NA	NA	137	137
Totals	336	21,316	14,551	35,867

( ) sub-entries

NA Not Applicable

(a) An establishment may be doing operations in more than one source category. Actually 280 establishments are sources.

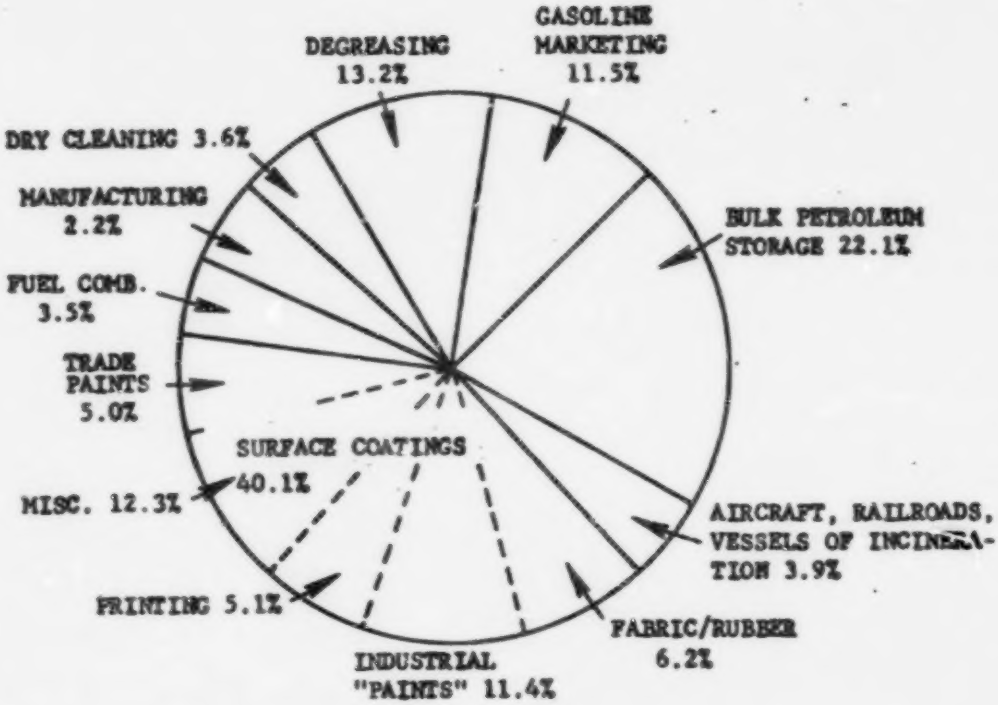


Figure 1. Distribution of total hydrocarbon emissions except from automobile travel (35,900 tons/yr) in Rhode Island

Table 7. HYDROCARBON SOURCES GREATER THAN 5 TONS/YEAR, 1973

For ____________________

Plant I.D.	Company	Emissions by source category (tons/year)								
					Surface coatings					
		Bulk storage	Dry cleaning	De-greasing	Fabric & rubber coatings	Paints	Inks	Other	Chem. mfg.	Fuel comb. & inc.

Table 8. SURVEY COVERAGE AND RESULTING EMISSIONS

		Region 1967 census or (1972 manuf. directory) data			No. of companies surveyed	Companies responding								Out of business or duplicate	Percent coverage (companies) surveyed	Percent coverage (employees) surveyed	Total estimated HC emis.
						Point sources			Area sources			Non sources					
SIC	Category	No. of companies	No. of co. > 20 empl.	No. of employees		No. of co.	No. of empl.	HC emis.	No. of co.	No. of empl.	HC emis.	No. of co.	No. of empl.				
22	Textiles 2231, 2295, 2297	(252)	187	3,700	57	19	2,766	3,981	4	400	10	22	1,339	12	100	100	3,991
24	Lumber	(38)	6	500	12	1	45	7	2	28	4	5	95	3	92	34	118
25	Furniture	(43)	7	700	21	0	0	0	10	51	7	10	36	1	100	12	103
26	Paper	(37)	32	2,800	41	5	852	2,237	12	517	16	21	876	1	95	89	2,827
27	Printing	(185)	38	4,400	99	9	1,978	252	63	2,142	19	13	1,192	11	97	100	293
28	Chemicals	(90)	25	3,000	53	7	1,445	732	25	750	37	14	635	5	96	94	843
29	Petroleum	(6)	--	300	2	2	145	15	0	0	0	0	0	0	100	45	15
30	Rubber	(84)	33	9,750	55	13	5,541	1,180	16	409	10	20	1,553	5	98	77	2,045
31	Leather	(18)	12	1,300	6	1	70	27	1	150	1	1	12	3	67	15	354
32	Stone, clay, etc.	(52)	14	2,500	3	1	600	19	0	0	0	2	100	0	100	24	29
33	Primary metals	(114)	40	9,700	78	8	1,444	373	9	365	8	54	1,872	7	100	62	696
34	Fab. metal prods.	(405)	89	8,500	253	33	3,115	1,160	52	1,044	82	124	2,364	25	92	77	2,016
35	Machinery	(272)	57	10,900	155	12	6,183	275	28	1,801	25	93	1,196	16	96	84	432
36	Elect. machinery	(61)	32	8,300	68	16	10,197	1,116	22	3,883	29	14	1,490	15	100	100	1,142
37	Transp. equip.	(28)	15	1,450	15	5	616	110	6	389	12	3	140	1	100	79	283
38	Instruments	(42)	15	4,100	13	2	815	56	4	206	3	7	476	0	100	37	212
39	Misc. Mfg.	(955)	227	24,200	136	43	10,142	1,000	41	3,381	80	27	2,155	18	96	65	2,524
	Subtotals	(2,733)	829	96,300	1,060	179	45,554	12,541	295	15,518	340	430	18,529	124	98	79	18,122
5153	Bulk storage	13 [a]	--	--	20	20	--	7,945	0	--	0	0	--	0	100	--	7,945
7215 & 7216	Dry cleaning	277 [b]	--	--	277	29	--	370	40	--	107	54	--	16	47	--	1,277
	Totals	3,023	829	96,300	1,357	228	45,554	20,856	335	15,518	447	484	15,529	140	86	79	27,343

[a] Source - Rhode Island Department of Public Health, Division of APC

[b] Source - Telephone Yellow Pages

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Table 8. SURVEY COVERAGE AND RESULTING EMISSIONS

SIC	Category	Region 1967 census or (1972 manuf. directory) data			No. of companies surveyed	Companies responding								Out of business or duplicate	Percent coverage (companies) surveyed	Percent coverage (employees) surveyed	Total estimated HC emis.
						Point sources			Area sources			Non sources					
		No. of companies	No. of co. > 20 empl.	No. of employees		No. of co.	No. of empl.	HC emis.	No. of co.	No. of empl.	HC emis.	No. of co.	No. of empl.				
22	Textiles 2231, 2295, 2297	(282)	187	3,700	57	19	2,766	3,981	4	400	10	22	1,339	12	100	100	3,991
24	Lumber	(38)	6	500	12	1	45	7	2	38	4	5	95	3	92	36	138
25	Furniture	(43)	7	700	21	0	0	0	10	51	7	10	34	1	100	12	303
26	Paper	(57)	32	2,800	41	5	852	2,237	12	317	16	27	876	1	95	80	2,827
27	Printing	(183)	38	4,400	99	9	1,978	252	63	2,142	19	13	1,192	11	97	100	299
28	Chemicals	(90)	25	3,000	53	7	1,465	732	25	750	37	16	635	5	96	96	843
29	Petroleum	(6)	--	300	2	2	163	16	0	6	0	0	0	0	100	48	16
30	Rubber	(84)	33	9,750	55	13	5,561	1,180	16	409	10	20	1,333	5	98	77	2,015
31	Leather	(18)	12	1,500	4	1	70	27	1	150	1	1	12	3	67	15	354
32	Stone, clay, etc.	(52)	14	2,500	3	1	600	19	0	0	0	2	100	0	100	24	39
33	Primary metals	(114)	40	9,700	78	8	1,444	373	9	365	8	54	1,872	7	100	62	690
34	Fab. metal prods.	(408)	89	8,300	253	33	3,115	1,160	52	1,044	82	126	2,384	25	92	77	2,016
35	Machinery	(272)	57	10,900	155	12	6,183	275	28	1,801	25	93	1,196	16	98	84	433
36	Elect. machinery	(61)	32	8,300	68	16	10,197	1,116	22	3,885	29	14	1,490	16	100	100	1,165
37	Transp. equip.	(28)	15	1,450	15	5	616	110	6	389	12	3	140	1	100	79	263
38	Instruments	(42)	15	4,100	13	2	815	56	4	205	3	7	476	0	100	37	217
39	Misc. Mfg.	(955)	227	24,200	136	45	10,142	1,000	41	3,381	80	27	2,155	18	96	65	2,524
	Subtotals	(2,733)	829	96,300	1,060	179	45,554	12,561	295	15,518	340	430	15,529	124	98	79	18,121
5153	Bulk storage	13 [a]	--	--	20	20	--	7,945	0	--	0	0	--	0	100	--	7,965
7215 & 7216	Dry cleaning	277 [b]	--	--	277	29	--	370	40	--	107	56	--	16	67	--	1,277
	Totals	3,023	839	96,300	1,357	228	45,554	20,856	335	15,518	447	484	15,529	140	86	79	27,363

[a] Source - Rhode Island Department of Public Health, Division of APC

[b] Source - Telephone Yellow Pages

on the selection procedure in Chapter IV, "Development of Mailing List." The responding information is obtained from the work sheets completed as questionnaires were returned. Hydrocarbon emissions are normally calculated by scaling up to 100 percent manufacturing employee coverage of the selected industrial categories (two-, three-, or four-digit SIC).

In certain cases no scale-up should be performed, because the number of responding companies or the number of reported employees exceeds the latest census information. Additional estimates and corrections are made by a careful analysis of each SIC and major category (dry cleaning, degreasing, printing, etc.). Statistical information or that obtained from major solvent suppliers should also be considered in any reestimation of survey information.

Point and Area Source Work Sheets

The point and area source work sheets are shown in Tables 9 and 10. They are completed as an intermediate step prior to summarizing the type and amount of hydrocarbon emissions by major category, city/county, or SIC. They are also useful for developing the NEDS point source structure and coding information. Control equipment type and efficiency, process type, and operating rate information may also be variables for other summaries.

An entry is made for each point source belonging to a major category such as dry cleaning, degreasing, etc. Processing equipment or method, industrial type and pollutant type are described to facilitate SCC selection and decoding. An attempt is made to select the appropriate SCC by hydrocarbon type or mixture, otherwise a catch-all SCC ending in 99 is chosen.

Table 9. POINT SOURCE WORK SHEET

Category_______________

NEDS ID.	NAME	CITY/CO	SIC	MFG. EMPL.	STUDY ID.	PT. ID.	PROCESS TYPE	CONTROL EQT.	EFF.	SCC	MATERIAL & OPERATING RATE	POLLUTANT	EMISSIONS (TONS/YR)

Table 10. AREA SOURCE WORK SHEET

Category____________________

Study ID	NAME	CITY/CO.	SIC	MFG. EMPL.	POLLUTANT	EMISSIONS (TONS/YR)

Summary of Hydrocarbon Emissions by Major Category, SIC and Pollutant

A table similar to Table 11 is constructed to analyze the hydrocarbon emissions by SIC and major categories. Point and area source emissions are given by SIC for each type of pollutant. The last few columns give the reported survey totals and the calculated nonreported survey totals. The nonreported survey total is estimated using percent survey coverage information and any additional estimates from national or regional figures. Any additional amount is apportioned to SIC's by the extent of the coverage and the reported hydrocarbon emissions within each SIC. A discussion on the method for estimating nonreported emissions for each category follows. Calculation procedures are only detailed in the paragraph entitled "Degreasing."

Degreasing - Trichloroethylene, perchloroethylene, and 1,1,1 trichloroethane are the solvents most commonly used for vapor and cold degreasing. Other solvents include methylene chloride, Stoddard solvent and lesser quantities of others (ketones, alcohols, aromatic compounds, etc.) which could be classified under "other." Companies classified within SIC codes 34 to 39 also account for most of the degreasing. Table 12 summarizes the results of the survey and the total non-reported emissions. The distribution of emissions from reporting sources, Table 13, is also useful for descriptive and planning purposes.

The non-reported emissions based on a 100 percent coverage in each SIC of the selected companies is calculated as follows:

$$\text{Non-Reported Emissions} = \frac{\text{(Reported Emissions)}}{\text{coverage fraction}} - \text{(Reported Emissions)}$$

$$E_{N-R} = E_{R/C} - E_R$$

This assumes that emissions are proportional to the total number of employees within the pertinent SIC codes.

Table 11. SAMPLE SHEET FOR THE ANALYSES OF TYPE OF HYDROCARBON EMISSIONS FOR STANDARD INDUSTRIAL CODES (SIC)

SIC	Type of source	Pollutants						Emissions reported E_R	% employee coverage C	Emissions non-reported E_{N-R}	Additional emission E_A	Total emissions E_T
20	Point (area)											
21	Point (area)											
22	Point (area)											
23	Point (area)											
24	Point (area)											
25	Point (area)											
26	Point (area)											
27	Point (area)											
28	Point (area)											
29	Point (area)											
30	Point (area)											
31	Point (area)											
32	Point (area)											
33	Point (area)											
34	Point (area)											
35	Point (area)											
36	Point (area)											
37	Point (area)											
38	Point (area)											
39	Point (area)											
5133	Point (area)											
7216	Point (area)											
Totals reported	Point (area)											
Estimated Totals	Point area											

Table 12. TYPE OF HYDROCARBON EMISSIONS VERSUS SIC FOR DEGREASING

SIC	Type of source	Pollutants						Emissions reported E_r	% employee coverage C	Emissions non-reported E_{N-R}	Additional emission E_A	Total emissions E_T
		Stoddard	Trichloro-ethane	Perchloro-ethylene	Methylene chloride	Trichloro-ethylene	Other					
20	Point (area)											
21	Point (area)											
22	Point (area)			34		6	(2)	40 (2)	1.0	(0)	0	40 (2)
23	Point (area)											
24	Point (area)											
25	Point (area)						(1)	(1)	.12	(7)	(3)	(10)
26	Point (area)	1	1				4	6	.80	(2)	(0)	6 (2)
27	Point (area)	3			2	3		9	1.0	(0)	(0)	9
28	Point (area)	(6)	8 (1)				(2)	8 (9)	.81	(4)	(1)	8 (14)
29	Point (area)											
30	Point (area)	(1)	30	23	74	(1)	12 (1)	139 (3)	.77	(42)	(10)	139 (55)
31	Point (area)		3			22		25	.15	(162)	(33)	25 (175)
32	Point (area)		5					5	.24	(16)	(4)	5 (20)
33	Point (area)	208	40 (1)	7		117 (3)	1 (1)	373 (7)	.62	(229)	(88)	373 (324)
34	Point (area)	37 (16)	425 (14)	71 (5)	2 (1)	407 (36)	2	944 (72)	.77	(303)	(71)	944 (446)
35	Point (area)	8 (8)	77 (6)	20	6	51 (6)		162 (16)	.84	(34)	(8)	162 (58)
36	Point (area)	18	106 (6)	44	13	104 (10)	7 (3)	292 (19)	1.0	(0)	(0)	292 (19)
37	Point (area)					42		42	.79	(11)	(3)	42 (14)
38	Point (area)	1	47	4		(3)		52 (3)	.37	(94)	32	52 117
39	Point (area)		62 (9)	138 (9)	48	476 (40)	7 (8)	731 (66)	.65	(428)	(100)	731 (594)
5153	Point (area)											
7216	Point (area)											
Totals reported	Point (area)	281 (31)	808 (35)	341 (14)	145 (1)	1228 (99)	46 (18)	2828 (198)				
Estimated totals	Point area	281 (199)	808 (690)	341 (206)	145 (80)	1228 (816)	46 (43)	2828 (198)		– (1292)	– (342)	2828 (1832)

Table 13. SIZE DISTRIBUTION OF HYDROCARBON EMISSIONS FOR DEGREASING

Emission range	No. of companies	Average size of company (employees)	Total emissions	Emissions, tons per year per employee
< 5 tons/year	135	< 150	143	0.02
5-25 tons/year	53	300	538	0.03
25-100 tons/year	9	830	470	0.06
> 100 tons/year	6	2400	1106	0.08
	—	—	2257	—

For purposes of comparison, emissions should be estimated by other methods. One method is to obtain trichloroethylene and 1,1,1-trichloroethane degreasing solvent usage from "Chemical Profiles"[12] or from the "Chemical Economics Handbook,"[13] and apportion them by any of these three indicators: manufacturing employees within 34 to 39 Codes, total manufacturing employees, or population. The above indicators are given in decreasing order of accuracy. Another method is to obtain total usage estimates from local suppliers who are well informed on marketing. Reasonable judgment should be exercised to determine any increase or decrease in the estimate depending upon coverage and any additional information known about the region. By choosing the higher estimate, the non-reported emissions figure would be conservative. The control strategies would be more stringent, requiring a slightly higher reduction.

If additional emissions are estimated for the region, they can be apportioned to SIC codes by the extent of the coverage and the quantity of reported emissions.

$$E_{A_i} = \frac{E_{Ri_{/Ci}} - E_{R_i}}{\sum_{i=1}^{n} (E_{R/C} - E_R)_i} = \frac{E_{N-R_i}}{\sum_{i=1}^{n} E_{N-R_i}}$$

where E_{R_i} = additional emissions for the ith SIC

E_{R_i} = reported emissions for the ith SIC

E_{N-R_i} = non reported emissions for the ith SIC based on a 100 percent coverage

C = coverage fraction

n = number of SIC categories

The total non-reported and additional estimated emissions are considered as area sources (non-identified point sources and area sources) and are reapportioned to pollutant categories by reported emissions. The total regional area source emissions will become the degreasing portion of the NEDS area source county entries "Solvent Purchased." This regional total is apportioned to counties by (1) non-responding 34 to 39 SIC manufacturing employees, (2) manufacturing employees in SIC 34 to 39, or (3) all manufacturing employees. The indicator is chosen in decreasing order depending on availability of census data.

Dry Cleaning - The emissions from this industry are due to two types of solvents; petroleum or Stoddard solvent and perchloroethylene. Perchloroethylene is used in much larger quantities than Stoddard, and about 80 percent of the perchloroethylene produced annually is used by dry cleaners. The remaining 20 percent is used for chemical intermediates and degreasing. All solvent purchased by dry cleaners is assumed to be evaporated.

Total estimated emissions from the survey are calculated based on 100 percent establishment coverage for the one SIC 7216. Three other methods are available for comparing perchloroethylene usage. The first method is based on dollar receipts spent on dry cleaning from the Census of Business.[14] The amount is calculated using conversion factors from the International Fabricare Institute.[15] In 1970, $1.50 was spent per 3.5 pounds of clothes cleaned and an average of 6.9 gallons of perchloroethylene is used to clean 1,000 pounds of clothes. The second method is based on estimates from major manufacturers and suppliers of dry cleaning solvents. They usually can provide information on regional usage. The third method is based on EPA consumption factors, 2 pounds of solvent evaporated per person per year, or 2.7 pounds per person per year for colder climates.[5]

Solvent usage by each county is determined by using the results of the point sources from the questionnaire and by proportioning the remaining estimated solvent used in this region. Two apportioning methods are available. The first method of proportionment is based upon the number of dry cleaners who did not respond to the questionnaire and an estimate of the population served by those establishments. The population served by the nonrespondents is determined by multiplying the fraction of dry cleaners that did not respond by the total population of that county. The second method assumes that each nonrespondent uses an equal amount of solvent, and apportions the remaining estimated solvent by the number of nonrespondents per county.

Surface Coating - This section will discuss the hydrocarbon emissions resulting from the application of coatings. This category doesn't include hydrocarbon emission resulting from chemical manufacturing, food and agricultural products manufacturing, petroleum refining, basic wood manufacturing, and textiles refinishing. Surface coating deals exclusively with applying a thin layer of coating on the surface. For purposes of discussion, it has been divided into four categories:

1. Fabric or rubberized coating
2. Protective or decorative coatings such as paints, lacquers, varnishes, etc.
3. Printing inks
4. Miscellaneous coatings such as adhesives and coatings for paper, leather, film and glass

Fabric or rubberized coatings - This section discusses and estimates the hydrocarbon emissions from establishments engaged in manufacturing coated and impregnated textiles, rubberized fabrics and other miscellaneous coated products such as insulating tapes and pipe wrap. The products are tailored from numerous decorative and/or protective polymeric coatings applied to a variety of fibrous, knitted, or nonwoven textile support webs using the following techniques:[16]

- Impregnation or saturation process
- Surface coating process with
    1. "Wet" or solvent-containing coatings
    2. "Dry" or hot melt coatings (casting)
    3. Lamination of preformed film

Although most polymeric compounds can be applied by any one of these methods, certain factors such as uniformity, esthetics, softness and protection enter into the selection of the process.

For example, in polyvinyl fabrics, the base layer is applied either by laminating the film or by casting the hot melt containing 5 percent solvent over a previously laid adhesive. An outer decorative layer, which contains ink, polymer, and about 80 percent solvent, is then coated "wet" by knife-over-roll. Only the saturation and "wet" surface coating processes use significant quantities of solvent which will then be emitted upon drying or curing the coated material.[24] Some of the solvents often used are toluene, naphtha, mineral spirits, and MEK. The classes of coatings often applied are: rubber, cellulose derivatives, polyvinyl, olefinic, polyester, acrylic, and polyurethanes. Sometimes epoxy or silicone adhesives are used to bind the coating to the fabric.[17] The emissions from them are included in this section.

The industries covered by this section are classified by SIC 22 (2231, 2295, 2297) and 30. Total emissions from each SIC category are scaled to 100 percent coverage according to manufacturing employees within each SIC. Since numerous types of coatings and application techniques exist, and any one coating can be used in large quantities in any one area or establishment, a national-to-regional breakdown is impractical. That portion of the total emissions not included in point sources is apportioned as area sources to counties by SIC 22 and 30 manufacturing employees. It is represented in the solvent purchased category.

Protective and decorative coatings (paints) - This section includes the application of paints, lacquers, varnishes, shellacs, primers, and enamels for protective or decorative purposes. This class of coatings is referred to by the industry as "paints" and are classified into two categories, industrial or trade paints. Industrial paints are products that are formulated and sold to other manufacturers (frequently in large containers) for factory application. Trade paints are shelf products that are sold through retail stores to the general public, professional painters, and builders. These products are largely architectural coatings for the outside and inside of new and existing structures. Industrial paints that are applied in large quantities at a fixed locations usually become classified as point sources. Non-point sources using industrial paints are accounted for in the "Solvents Purchased" entry of the NEDS area source file. Trade-sale paints are by definition exclusively area sources and are included in the last section. But, because the emissions are estimated by the same method and are also represented in NEDS by the field "Solvent Purchased," they are discussed here.

Paints are applied by brushing, spraying, rolling, flow coating, or dipping. Industrial paints are used in the manufacturing industries, SIC 24 to 39, and automotive repair shops, SIC 75. Automotive repair shops are almost always area sources, although if the methodology as described in previous chapters is followed, some large auto body shops should be contacted. As before, total emissions are estimated from a national-to-regional breakdown because of several factors, including the inavailability of records of the quantities of the many types of paints purchased, and information concerning the percentage of solvent content in the purchased paint and the actual paint applied.

The methodology for estimating total paint solvents emitted from national figures to regional figures involves the use of two reference sources and some assumptions about the density and average solvent content in paints. The "Chemical Economics Handbook"[13] provides national estimates of industrial paint sale volume, solvent based trade sale paint volume, and total solvent usage in paint. From this information it is possible to determine relative solvent emissions from industrial and trade sale paints, if an average weight per gallon and average solvent content could be determined for regional industrial or trade paints. Unfortunately, definitive information regarding the above is not always available from local industrial manufacturers and suppliers. If we can consider the survey results as representative, then industrial paints average about 9 lb/gal and 67 percent solvent. Using the CEH figure of 400 x 10^6 gallons of industrial paint, then 1,200,000 tons of solvents were emitted in the United States during 1970 from industrial paint. Since CEH reports that 1,700,000 tons of solvents were used in 1970, then 500,000 tons must have been used in solvent-based trade paints. Solvent content of the 937,000 tons of solvent-base trade paints would average 53 percent which is perhaps somewhat high. Water-based trade paints contain about 3.5 percent volatile hydrocarbons and for 1970 would emit 50,000 tons of hydrocarbons. National emissions can be estimated for a different base year using growth rates also given in the above reference.

Although regional apportioning factors could be based on manufacturing employees for industrial paints and population for trade paints, the National Paint and Coating Association (NPC)[18] publishes a percentage breakdown of industrial and trade paint usage for nine U.S. regions. The last survey accounted for almost one-half of the national sales. The U.S. Census of Transportation also publishes similar figures about every five years. Tables 14 and 15 compare the breakdowns for industrial and trade paints obtained from NPC, 1967 census, and those calculated from regional population and manufacturing employees. Although the methods show good agreement only for some regions, the latest NPC survey or census figures should be applied. They are the only direct measures of regional paint sales.

To obtain state, county, or study area figures, regional figures can then be apportioned by manufacturing employees for industrial paints and by population for trade paints.

Printing - The printing ink industry is another surface coating category that uses solvents. There are five basic types of printing operations:

Table 15. PERCENTAGE BREAKDOWN OF INDUSTRIAL PAINT SALES FOR U.S. REGIONS

	1972 NPC	1967 Census minus NPC trade (adjusted to 1967)	1967 Manuf. emp.
New England (Me., N.H., Vt., Mass., R.I., Conn.)	3.0	3.7	8.0
Middle Atlantic (N.Y., N.J., Pa.)	10.9	11.9	22.8
East North Central (Ohio, Ind., Ill.)	29.4	31.9	26.8
West North Central (Minn., Iowa, Mo., Kans., N.D., S.D., Neb.)	7.1	10.9	6.2
South Atlantic (Del., Md., D.C., Va., W.Va., N.C., S.C., Ga., Fla.)	19.3	12.7	12.8
East SouthCentral (Ky., Tenn., Ala., Miss.)	8.9	11.0	5.7
West South Central (Ark., La., Okla., Texas)	7.0	14.0	5.6
Mountain (Mont., Idaho, Wyo., Colo., N.M., Ariz., Utah, Nevada)	1.3	1.6	1.6
Pacific (Wash., Ore., Calif., Alaska, Hawaii	13.1	2.2	10.5

letter-press, flexographic, gravure, lithographic, and screen. Whether or not hydrocarbon emissions occur depend on the particular type of ink used for particular methods of application. However, certain types of inks are often used with certain methods. Table 16 indicates the range of percent solvent content in inks for two drying methods versus the five printing processes.[16,19,20]

Table 16. PERCENTAGE OF SOLVENT CONTENT FOR TWO DRYING METHODS VERSUS FIVE PRINTING PROCESSES

Drying method	Letter-press	Flexographic	Litho-graphic	Gravure	Screen
Evaporation	--	Solvent base (40-75%)	--	40-75%	0-60%
Heat set	~10%	Water base (0-30%)	~16%	--	0-60%

The flexographic and gravure process account for approximately one-third of all inks used. They mainly use solvent-based inks containing 40 to 75 percent solvent, which is then evaporated on drying. Water-base inks are also coming into use in the flexographic process. Some of these water-base inks also contain solvent (0 to 30 percent) for faster drying. The screen process uses oil and lacquer-type inks which contain 0 to 60 percent solvents. However, this class accounts for less than 6 percent of the national total solvent used for inks. Letterpress and lithographic inks, which account for about one-third of the total inks used, are oil-based and emit some solvents when heat-set letterpress or heat-set web offset is used. Alcohol type solvents are also used in the water fountain for the lithographic process.

Oil based inks are mostly used in publications of periodicals and books and in commercial printing, whose SIC is 27 (272 and 275). Flexographic and gravure printing, which use mainly solvent-based inks, is mostly used in making miscellaneous converted paper products and paper-board containers, whose SIC is 26 (264 and 265).

Printing hydrocarbon emissions are scaled to a 100% coverage by manufacturing employees. They can be compared to national figures apportioned to the study area. National total solvent used by the printing industry is found in the "American Inkmaker."[21] Applying a 7 percent annual growth rate on the 1967 figures the solvent usage breakdown is given in Table 17.

Table 17. NATIONAL SOLVENT USAGE (TONS/YEAR)

	1967	1973
Oil inks	25,000	37,000
Flexographic/gravure	55,000	83,000
Other	5,000	8,000

The oil-based ink solvent is apportioned by manufacturing employees in SIC 27, and the flexographic/gravure and other solvent is apportioned by manufacturing employees in SIC 26. The results are compared with the survey figures respectively by SIC. Additional regional information about printing is also considered. Any "additional" emissions are redistributed to SIC's and the area source total is apportioned to counties by the indicator used in this section.

Miscellaneous Surface Coatings - This category encompasses the infrequent operations such as the treatment of paper (SIC 26), refinishing of leather (SIC 31), manufacture of magnetic tapes and fluorescent tubes (SIC 36), manufacture of photographic films (SIC 38) and adhesives operations in any other industries not covered above.

Paper is usually "converted" to end products by such treatments as embossing, impregnating, saturating, and lamination. The two classes of coatings used are pigment coatings and barrier coatings. Hydrocarbon emissions occur from the adhesives that bind the pigment, and from the solvent acting as a vehicle in the barrier coatings.

Finishing of leather involves the application of film-forming materials to the grain to provide abrasion and stain resistance and the enhancement of color. Previously leather coatings were restricted to casein, shellac, albumin, wax, and linseed oil. However, today more sophisticated film-forming polymeric substances are used and applied by rotary brush, flow coaters and rotary sprayers. Organic solvents are used as dilutents for the polymeric coatings and are then emitted during the drying stages.[22] The industries that use leather and allied products for the manufacture of shoes and furnishings are also a source of hydrocarbon emissions due to solvents in the adhesives.

If the firms covered by these industries are numerous and not all were surveyed emissions should be scaled by respective SIC manufacturing employees. If, however, it is known that only a few companies are doing these operations hydrocarbon emissions should not be scaled. Some of these rare operations are the manufacture of magnetic tapes, fluorescent tubes and photographic films. The first two involve the application of inorganic particles (iron oxide, fluorescent compound) dispersed in a solvent on to a base (plastic, glass) and the evaporation of the solvent by drying.

Photographic films are coated with polymeric dispersions and solutions which contain solvents. These solvents act as a vehicle to uniformly apply the matrix of layer on to the plastic base film, and are later evaporated and emitted to the atmosphere.

Hydrocarbon Emissions From Manufacturing Not Including Surface Coating and Degreasing - Hydrocarbon emissions from this category occur when the raw or intermediate material, itself, contains hydrocarbons of which some or all may be driven off, or when hydrocarbon compounds are reacted or mixed with the raw or intermediate material. This category can nicely be broken down by SIC industrial classes for discussion purposes. Table 18 gives the type of processes which emit hydrocarbons.

Table 18. PROCESSES EMITTING HYDROCARBON FROM MANUFACTURING

SIC	Description	Processes
20	Food & agricultural products	Fermentation & distillation of alcoholic beverages
22	Textile mill products	Dyeing and finishing
25	Lumber & wood products	Veneer drying
28	Chemicals & allied products	Organic chemical manufacturing Surface coatings manufacturing Specialty chemical manufacturing
29	Petroleum refining and related industries	Petroleum operations except asphalt mixing
30	Rubber and miscellaneous plastic products	Plastic and rubber products operations
31	Leather and leather products	Leather refinishing
32	Mineral products	Asphalt roofing Asphalt mixing
33	Primary metal industries	Coal and coke processing
34-39	Machinery and other consumer products	Fabrication of plastic or resin products: fiberglass boats, toys, etc.

For manufacturing categories, total hydrocarbon emissions should be scaled only when numerous companies are doing the operations described in the above table. National consumption or production of certain products are of little value for regional breakdown, because the companies are likely to be relatively few and unevenly distributed in the United States compared to those doing surface coating, degreasing or dry cleaning. Except for petroleum refining and certain chemical processing operations, the hydrocarbon emissions from these manufacturing operations are relatively small as compared with surface coating.

Bulk Storage of Petroleum and Petrochemical Products - Hydrocarbon emissions from three operations, the filling, storing and emptying of various types of tanks, by the manufacturing industry, oil companies, distributors, utilities and airports are considered here. Most of these three operations are point sources and are coded into NEDS. For example a fixed roof tank might regularly be filled by a marine vessel and emptied by truck. Storage emissions would be both from breathing and working losses. Evaporative area sources are relatively few and are neglected by the NEDS area source form. Gasoline, the only petroleum product emitting significant quantities of hydrocarbons at the retail level, is discussed in a later section on "Exclusively Area Sources Emitting Hydrocarbons."

The data summary tables are different for this category. Table 19 is a good way to represent the data. For each type of operation (or operating variable) the emissions from each type of petroleum product are entered. Emissions are calculated using EPA emission factors.[11]

Emphasis has been placed on obtaining information from all bulk storage sites because they are relatively few in number. This is also important because the emissions can only be recorded as point sources. A check on the questionnaire information can be made by obtaining petroleum transfer at ports published by "Waterborne Statistics."[23] The Army Corps of

Table 19. HYDROCARBON EVAPORATIVE LOSSES AT BULK STORAGE SITES

Operation	Gasoline	Distillate oil	Jet fuel	Kerosene	Diesel	Total emissions by operation
Marine vessel-						
Unloading	858	81	9	3	2	953
Loading	115	8	2	1	1	127
Tank cars/trucks-						
Splash loading	915	75	34	1	--	1025
Submerged loading	1409	88	1	9	10	1517
Unloading	314	--	--	--	--	314
Storage/fixed roof						
Breathing loss	1045	1140	99	71	12	2367
Working loss	807	297	52	25	4	1185
Storage/floating roof						
Standing loss	369	11	0	0	2	382
Storage/variable vapor space						
Working loss	0	0	0	0	0	0
Total emission by product	5832	1700	197	110	31	7870

Engineers records (foreign, coast-wise, internal and local) receipts and shipments of major petroleum products. A flow diagram and material balances for each product can clearly indicate the storage and transport patterns of the region. The sum of the transports at each entry or source place can now be compared. A significant difference would indicate review of the possible storage sites in number and in the accuracy of the information provided.

Exclusively Area Sources Emitting Hydrocarbons

These sources are almost always considered area sources because either they are relatively small emitters and numerous, or they are mobile. This category consists of evaporation from application of trade paints, evaporation from gasoline marketing, combustion of fuels in transportation, non-highway use of motor fuels, and combustion of miscellaneous sources. Area sources from stationary fuel combustion and solid waste disposal have already been mentioned in the beginning of this chapter. The methods for gathering this information is well documented in the "Guide for Compiling a Comprehensive Emissions Inventory," APTD 1135.[5] We will therefore only comment on the first three listed above.

Evaporation From the Application of Trade Paints - The methodology for estimating and apportioning the emissions to counties has already been discussed in the section on Protective and Decorative Coatings--Paints. The emissions from trade paints along with all other process and evaporative hydrocarbon area source emissions are entered in the "solvent purchased" entry in NEDS for each county.

Evaporation From Gasoline Marketing - Gasoline is the only one of the petroleum products, which is emitted in significant amounts through retail marketing. A diagram of gasoline flow can be completed using the information given in an earlier section on bulk storage and other references found in the methods for estimating county on-highway motor vehicle and off-highway gasoline in "A Guide for Compiling a Comprehensive Emissions

Inventory," APTD-1135.[5] Figure 8 is the flow pattern found in Rhode Island. The NEDS entry on county gasoline marketed is the sum of on-highway and off-highway gasoline use. Calculation methods are also documented in APTD-1135. Evaporative emissions are calculated using an overall emission factor which is the summation of emission factors from five gas station operations. Emission factors are adjusted for an average gasoline vapor pressure. The operations and emission factors at 4.6 psia vapor pressure are given in Table 20.

Table 20. EMISSIONS: LOSSES PER 1000 GALLONS TRANSFERRED

Operation	Pounds
Tank truck unloading	1.6
Storage tank fill (splash)	9.2
Storage tank unloading	0.8
Vehicle fill	8.8
Gasoline spillage	0.6
Total	21.0

Transportation - This is the largest hydrocarbon source and the accuracy of the methodology for estimating the emissions is important. Methods for estimating the emissions are also given in APTD-1135 for all transportation classes, motor vehicles, aircraft, railroads and vessels. Since motor vehicle emissions are by far the largest, the methodology given in "An Interim Report on Motor Vehicle Emission Estimation"[24] should be followed. Although this requires more information gathering and processing, it estimates the emissions more accurately.

Miscellaneous Hydrocarbon Area Sources - Hydrocarbon emissions from these sources are relatively small to the total for most cases. APTD-1135 describes the methodology for estimating the following:

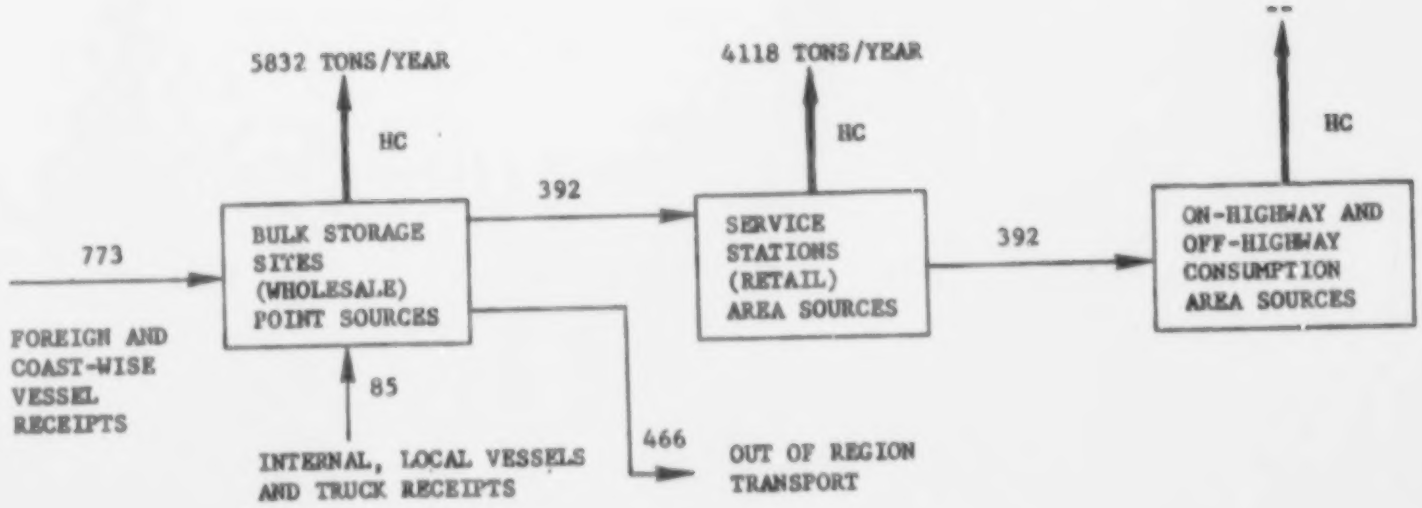

5832 TONS/YEAR
HC
4118 TONS/YEAR
HC
--
HC
773
BULK STORAGE SITES (WHOLESALE) POINT SOURCES
392
SERVICE STATIONS (RETAIL) AREA SOURCES
392
ON-HIGHWAY AND OFF-HIGHWAY CONSUMPTION AREA SOURCES
FOREIGN AND COAST-WISE VESSEL RECEIPTS
85
INTERNAL, LOCAL VESSELS AND TRUCK RECEIPTS
466
OUT OF REGION TRANSPORT

Figure 4. Gasoline flow (10^6, millions of gallons) and resulting hydrocarbon (HC) emissions for the State of Rhode Island.

- Non-highway use of motor fuels
- Acres and quantity of wood burned by forest fires
- Acres and quantity of material burned by slash and agriculture fires
- Structural fires
- Number and size of active coal refuse piles.

EPA emission factors are applied for calculating hydrocarbon emissions.

COMPUTER DATA HANDLING SYSTEM

The development of a computer data handling system involves coding the information onto standard forms and programming the storage/retrieval, processing and report generating functions. The present National Emission Data System (NEDS) has been extensively developed to include and accommodate these functions. It remains to modify and add any deficiencies in coding hydrocarbon point and area source information, and to write the program(s) necessary to generate the tabular summaries found in the "Manual Approach." In this report, only the methodology for generating the summaries is described. The computer programs are not provided.

Survey Coverage and Emission Summary Table

The establishment identification card described earlier for labels, and a response card can be coded for entry into the computer.

The identification card contains the following information:

- plant identification number
- county, AQCR, city codes
- SIC
- name and address

The additional information required to complete the summary table would be on the response card:

- type of source (P, A, N, O, b̸)
  P = Point source; A = Area source; N = Not a source;
  O = Out of business; b̸ = blank, non-respondent
- number of manufacturing employees
- emissions (tons/year) by major category
- Q, T; Questionnaire, Telephone information.

The response card can be completed as the questionnaires or telephone information is received. In addition, the identification information should be verified.

Then a single computer program could read, process and summarize the data in various formats:

- SIC versus coverage by number of establishments, manufacturing employees, source type, and emissions
- Emissions by SIC for each major category
- Listing of non-respondents for enforcement
- Listing of telephone respondents for further verification
- Listing of point sources by city, county, AQCR, SIC, size, etc.

The above summaries can then be used to estimate total hydrocarbon emissions and to compare them with estimated study area figures broken down from national figures by some indicator. Any additional emission estimates would be coded into the area source form. All other area sources emitting hydrocarbons would also be reviewed.

Coding of NEDS Point Source Form

Point source information is coded on NEDS and made available to the many federal and private agencies either in computer readable form or in printout listings and summaries. Coding instructions are found in the "Guide for Compiling a Comprehensive Emission Inventory" - APTD 1135[5] and will not be repeated here.

The information concerning hydrocarbon species is not adequately being handled by NEDS to generate the summaries described in the "Manual Approach," or needed for the proper evaluation of the regulations. Four major categories, dry cleaning (SCC: 401001), degreasing (SCC: 401002), petroleum product storage (SCC: 403) and petroleum marketing-transportation (SCC: 406) have an adequate number of SCC's to calculate the type and quantity of hydrocarbon emitted. Other categories, such as the subcategories in surface coating (SCC: 402) (fabric coating, protective or decorative coatings - paints, printing (SCC: 405), miscellaneous coatings for glass, paper, leather, etc.), food/agricultural industries, chemical manufacturing industries (SCC: 301), wood products (SCC: 307), petroleum industry (SCC: 306), leather products (SCC: 320) and textile manufacturing (SCC: 330) do not have adequate SCC's to describe the process and type of material used.

Generation of Emission Tabular Summaries

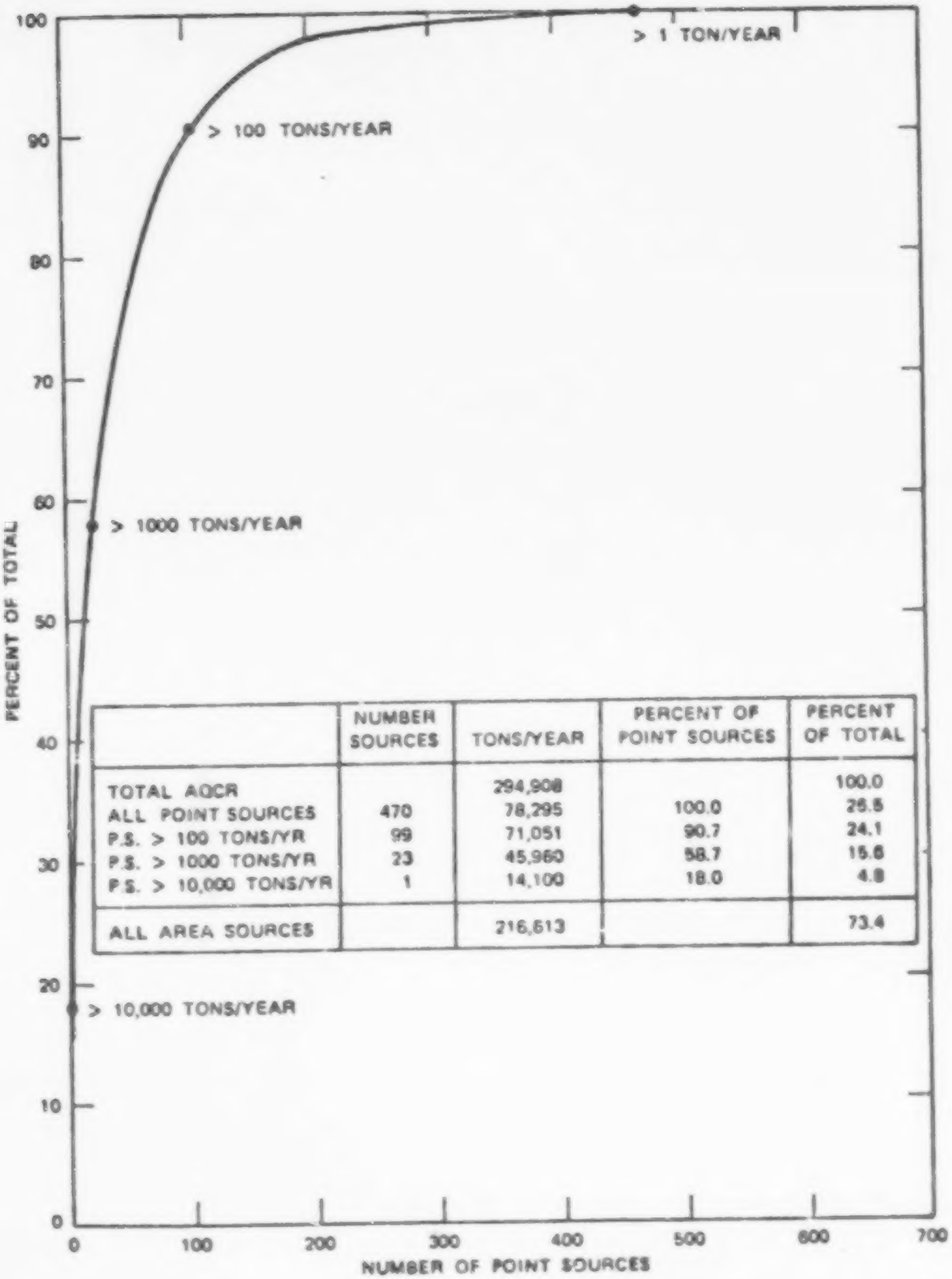
Once the point source information is loaded into the NEDS data files, the hydrocarbon emission tabular summaries described in the "Manual Approach" of Section V can be produced with a computer program. This could be performed by NEDB or outside by the agency performing the study. As indicated earlier, the SCC codes along with other information in the files would be retrieved for classification. It is expected that the classification will assist in the evaluation of control strategies to meet the oxidant air quality standard.

CHAPTER VI

APPLICATION OF THE HYDROCARBON METHODOLOGY TO THE REGIONAL AIR POLLUTION STUDY

The methodology for inventorying hydrocarbons is a detailed plan to acquire a very extensive data bank. The data will be in much greater detail as to the character of emissions than has been achieved before on a regional scale.[25] In the St. Louis Regional Air Pollution Study (RAPS), the data is needed for the development and validation of mathematical simulation models of air pollution processes. The models are formulations of all of the atmospheric processes such as convective transport, diffusion, physical and chemical transformation, and removal of pollutants. Two models that deal with hydrocarbons are presented in "Urban Air Shed Photochemical Simulation Model Study"[26] and in "User's Guide to Diffusion/Kinetics (DIFKIN) Code."[27] The number of pollutants considered by the models are relatively few, but can be increased as more information is known. For example, more rate constants and stoichiometric coefficients are being estimated for hydrocarbon reactions. Time is an important variable allowing consideration for specific short time intervals.

Several emission inventories have been conducted in the St. Louis area. The NEDS inventory is the last and most recent inventory. The data was originally transferred from the other inventories in the summer of 1973, and will be updated quarterly by the state agencies. It is evident that NEDS is increasing the degree of sophistication and usefulness for planning purposes. A recent analysis of the hydrocarbon emissions inventory for the St. Louis AQCR is shown in Figure 9.[28]



	NUMBER SOURCES	TONS/YEAR	PERCENT OF POINT SOURCES	PERCENT OF TOTAL
TOTAL AQCR		294,908		100.0
ALL POINT SOURCES	470	78,295	100.0	26.5
P.S. > 100 TONS/YR	99	71,051	90.7	24.1
P.S. > 1000 TONS/YR	23	45,960	58.7	15.6
P.S. > 10,000 TONS/YR	1	14,100	18.0	4.8
ALL AREA SOURCES		216,613		73.4

Figure 9. Hydrocarbon emissions for the Saint Louis Air Quality Control Region.[28]

Point sources account for 78,295 tons/year of the total 294,908 tons/year for the AQCR. In addition, only approximately 100 point sources account for 90 percent of the total point source emissions. A total of 470 point sources were coded. Previous studies of hydrocarbon emissions in other areas do not indicate an extensive cataloging of the amount and type of hydrocarbon species. Also, as the effort is increased to obtain more accurate data and more point sources, there is an increase in the percent of the emissions that can be attributed to point sources and monitored for control. Referring to Figure 9, the curve would shift down and to the right, and the points on the curve (e.g., > 100 tons/year) would also shift down.

In summary, the application of this methodology to the St. Louis RAPS program would not only catalog the hydrocarbon emissions by amount and type, but would increase the accuracy of the inventory, describe the emissions by source category and give the emission rates over specific short time periods. To achieve these goals, there are three areas of the methodology discussed in previous Chapters that need more development for the RAPS program than required by most regions. These are:

- Inclusion of smaller point sources
- Delineation of hydrocarbon species for point and area sources
- Determination of hourly emission estimates.

The methodology allows for the inclusion of point sources to any degree of refinement necessary by the RAPS program. The smallest point source that can be coded in NEDS is 1 ton/year. There are several criteria for selecting the emission size that distinguish between point and area sources. Since it takes more time to maintain information on point sources than area sources, the availability of funds is a factor. Another factor would be the percent of emissions required to be monitored by the program. Once again, the economics and the degree of accuracy are important. It ordinarily follows that the higher the percent of emissions monitored the more accurate the inventory becomes. The precision of the inventory is important for the validation of the simulation models. Another factor to be considered for classifying a point source is whether it can be controlled by the existing or proposed regulations.

Previous chapters have already mentioned that the development of new Standard Classification Codes (SCC) for NEDS will be the partial solution for defining the process and the type of hydrocarbon species being emitted. The SCC file has been designed to include new codes as they are being developed. As they are developed, the general codes which end in 99 can be shifted to these newly defined ones. The photochemical reactivity of these hydrocarbon species can then be considered in the simulation models and the models can then estimate the formation of photochemical oxidants based on the quantity of reactants, reaction rates and amount of energy from sunlight. It should be noted that the methodology discussed in Chapter V already provides for point and area source classification by pollutant, an example of which has been presented in Table 11. Similar tables can be provided for all major categories of hydrocarbon sources and utilized in RAPS programs.

The third area is the development of techniques by which the inventory can be used to estimate emissions over specific short time periods. These techniques should be used when processing or summarizing the information in the data bank. Estimating emissions down to the hourly level, or defining the daily and weekly emission cycle will support the short time simulation modeling efforts. This is very important because the formation of photochemical oxidants occurs during sunlight hours, and is dependent upon the concentration of hydrocarbons during this time. The basis for the NEDS inventory is one year, however, the point source quarterly percent thruput and the number of normal operating hours are recorded for further breakdown of emissions. It is apparent that some of the hydrocarbon emissions are dependent on the working hours at the establishment. For example, a typical commercial dry cleaner starts work around 7:00 to 8:00 a.m. and operates for 8 to 10 hours. On the surface, the program which estimates hourly emission rates should have hydrocarbons emitted only for the operating hours beginning on the seventh to eighth hour of the day. On the other hand, hydrocarbon emissions from a fixed roof tank occur throughout the day and are dependent on several factors such as temperature, absorption of sunlight, and displacement of the liquid level through transfer operations.

In any event, it is apparent that the NEDS form and the methodology discussed previously here (see page 1 of the questionnaire in Table A-1) do not directly address the question of the daily period of operation and/or emissions. It can be inferred in most instances that sources specifying an 8-hour operation do so over a normal 8:00 a.m. to 5:00 p.m. period. However, to cite the previous examples, a dry cleaning operation may report an 8 to 10 hour operation yet perform much of its cleaning after the closing of its doors to commercial operation. Similarly, in the case of gasoline storage and distribution operations, much of the emissions due to transfer activity may take place throughout the evening.

Most other categories, however, will emit hydrocarbons which will be proportional to the number of operating hours as reported. Most larger emitters will operate and emit on a continuous basis. This will be true for most surface coating operations, power generating plants, large-scale degreasing, printing plants, etc. However, other manufacturing operations may be categorized as cyclic or batch type. These could include many small manufacturing operations and certain process operations, such as batch type coating formulation, plastic and adhesive manufacture, Kraft pulp digestion, blowdown operations at refineries, etc. Their cycles may occur at regular intervals or possibly exhibit hourly, daily, or long term variations due to product demands.

Obviously, when cyclic operations are random or irregular in occurrence, the situation is complex. The importance of such variations, however, may not be serious in that they may be small compared to the overall contributions of temporally definable sources. Nevertheless, the question should be addressed. From the standpoint of the methodology, some modification of the questionnaire should be considered. This would involve the supplementation of existing NEDS information concerning season and normal operating schedules with hourly information. The respondent could be requested to estimate the fraction of sources emitted hourly or at specified intervals of the day: 12 to 6 a.m.; 6 a.m. to 12 p.m.; etc. This estimation could follow a notation as to whether emissions are continuous, cyclic, or irregular, as below:

Emission Cycle:

Continuous ____ Batch ____ Irregular ____

Approximate Percentage of Emissions
Occurring During the Day

12 a.m.-6 a.m.	6 a.m.-12 p.m.	12 p.m.-6 p.m.	6 p.m.-12 a.m.

This information should be included preferably throughout the questionnaire to satisfactorily cover plants engaged in multiple operations. Although this methodology is cumbersome and may prove to be an over-refinement of the methodology depicted in Chapter V, it appears to be the only way of determining hourly emission variations.

The problem of diurnal variations of emissions from storage operations can be treated mathematically based on temperature vapor pressure considerations in much the same manner as seasonal variations. To determine distribution losses due to transfer operations, however, again some assessment of hourly activity must be made. This information could be requested on the questionnaire supplied to the principal gasoline distributors.

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APPENDIX A

QUESTIONNAIRE

Table A-1. QUESTIONNAIRE TO MANUFACTURING INDUSTRIES AND DRY CLEANERS

official use
Rec. by________Date:____
SIC________
X,Y________

I. GENERAL INFORMATION

A. Company Name________
Plant Address________City________Zip Code________
Nearest Street Intersection________
Mailing Address________City________Zip Code________

B. Person to contact about form________
Telephone________Title________

C. Approximate number of employees________

D. Nature of Business________

E. Normal Operating schedule
________Hrs./day________days/wk.________wks/yr.

F. Approximate Percent Seasonal Operation:

Dec.-Feb.	Mar-May	Jun-Aug	Sept.-Nov.

G. Are volatile organic or solvent-containing materials such as cleaning fluids, coatings, adhesives, inks, etc. used in your operation? ____ Yes ____No

If NO, sign form and return

If YES, sign form and complete only the sections pertaining to your operation:

	Page
II. Dry Cleaning	2, 9 & 10
III. Degreasing	3, 9 & 10
IV. Surface Coating Applications	
A. Fabric and Rubberized	4, 9 & 10
B. Protective or Decorative other than IV-A	5, 9 & 10
C. Printing	6, 9 & 10
D. Miscellaneous Surface Coatings (Adhesives, Paper, Leather, films, Glass etc)	7, 9 & 10
V. Manufacturing Industries	8, 9 & 10

Signature ________ Date ________

II. DRY CLEANING

A. Amount of clothes cleaned per year ________________ tons.

B. Type of dry cleaning unit ☐ hot or dry-to-dry

☐ cold or transfer

C. Type and amount of solvent cleaner purchased in 1973.

Perchloroethylene ______________________ Gal./Yr.

Stoddard solvent ______________________ Gal./Yr.

Other (specify) ______________________ Gal./Yr.

Other (specify) ______________________ Gal./Yr.

D. Supplier of solvent - Name and address

Perchlorethylene ______________________________

____

Stoddard Solvent ______________________________

____

Other (specify) ______________________________

____

Other (specify) ______________________________

____

E. Please complete Section VI, page 9.

If you have any questions about this section please contact:

Mr. Roger Schilling
Field Representative for
International Fabricare Institute
5 Shawsheen Ave.
Bedford, Mass.
(617) 275-7583

III. DEGREASING OPERATIONS

A. Type of degreasing: ☐ cold solvent cleaning
☐ vapor degreasing

B. Type and amount of solvent purchased for degreasing operations.

1) Stoddard ____________ Gal./yr.
2) 1,1,1-Trichloroethane (Chlorothane VG) ____________ Gal./yr.
3) Perchloroethylene ____________ Gal./yr.
4) Methylene chloride ____________ Gal./yr.
5) Trichloroethylene ____________ Gal./yr.
6) Other (specify) ____________ Gal./yr.
7) Other (specify) ____________ Gal./yr.

C. Suppliers of Solvents

____
____

____
____

____
____

D. Waste solvent disposal method

____

E. Amount of each solvent returned for reprocessing to vendor or collector

1) Stoddard ____________ Gal./yr.
2) Trichloroethane ____________ Gal./yr.
3) Perchloroethylene ____________ Gal./yr.
4) Methylene chloride ____________ Gal./yr.
5) Trichloroethylene ____________ Gal./yr.
6) Other (specify) ____________ Gal./yr.
7) Other (specify) ____________ Gal./yr.

F. Please complete Section VI, page 9.

IV-A. FABRIC OR RUBBERIZED COATING APPLICATION

(1) Material(s) being coated ______________________.

(2) Type of coating process:

Source No.[*]	State Coating Process: Impregnation, "Wet" Coating, Hot Melt Coating, Lamination	Type of Coating[**]	Amount of Coating (Gal/Yr)	Type[†] and % of Vehicle Solvent		Type[†] and Amount of Solvent Added to Coating (Gal/Yr)	

(3) Type[†] of cleaning solvent ______________________, Amount ______________ (Gal/Yr)

______________________, Amount ______________ (Gal/Yr)

(4) Is any solvent returned to supplier or collector?

_____No _____Yes Type[†]______________, Amount ____________ (Gal/Yr)

(5) Please complete Section VI, p. 9; use same Source No.

---

[*] A source is an individual or similar pieces of equipment such as coaters, dryers, etc. It should correspond to the Source No. on page 9. If applicable, it should also correspond to previously reported sources in "Air Pollution Emissions Report" (Form 138-R75)

[**] Polyvinyl chloride, polyurethanes, etc.

[†] Toluene, naphtha, mineral spirits, MEK, xylene, chlorinated hydrocarbon, other (specify).

IV-B. PROTECTIVE OR DECORATIVE COATINGS OTHER THAN FABRIC COATING

1. Indicate material being coated ______________________________
____

2. Type and amount of coating used:

Source* Number	State Application Method: Spraying, Dipping, Roller, Flow, etc.	Type of Paint**	Amount Gals./yr.	% solids	Type† and % of major solvents	

3. Type† and amount of thinner used for dilution and cleaning not included above

______________________, Amount______________________Gal./yr.
______________________, Amount______________________Gal./yr.

4. Please complete Section VI, page 9.

---

[*] A source is an individual or similar piece of equipment such as spray booths, tanks, dryers, etc. It should correspond to the Source No. on page 9. If applicable, it should also correspond to previously reported sources in "Air Pollution Emissions report" (Form 158-R75)

[**] (1) paint, (3) varnish/shellac, (4) lacquer, (5) enamel, (6) primer

[†] If known, - acetone, isopropyl alcohol, MEK, butyl acetate, cellosolve, toluene, etc.

IV-C. PRINTING

(1) Material being coated ______________________________

(2) Type of printing process:

Source No.[*]	State Printing Process: Letterpress, Flexographic, Lithographic, Gravure, Screen	Type of Ink[**]	Amount (lb/yr)	Type[†] and % of major solvents in ink	

(3) Type[†] and amount of solvent used for dilution and cleaning not included above: ________________ Amount __________ Gal./yr.

________________ Amount __________ Gal./yr.

(4) Please complete Section VI p.9 ; ; use same Source No.

---

[*] A source is an individual or similar printing machines, dryers, etc. It should correspond to the Source No. on page 9. If applicable, it should also correspond to previously reported sources in "Air Pollution Emissions Report" (Form 158-R75).

[**] Solvent based, oil based, lacquer-type, etc.

[†] Isopropyl alcohol, Ethanol, Propanol, Naphtha/Mineral Spirits, Toluene, MEK, other (specify)

IV-D. MISCELLANEOUS SURFACE COATING APPLICATION
(Adhesives, Paper, Leather, Films, Glass, etc)

(1) Material(s) being coated ______________________________

(2) Type of coating process:

Source No.*	State Coating Process: Spray, Flow, Dip, Roller, Brush, etc.	Type of Coating**	Amount of Coating (Gal/Yr)	Type# and % of Major Solvents in Coating	

(3) Type# and additional amount of solvent used for dilution and cleaning not included above ______________, Amount ____________ Gal/Yr.
______________, Amount ____________ Gal/Yr.

(4) Please complete Section VI, page 9 ; Use the same Source No.

---

[*] A source number is an individual or similar pieces of equipment using surface coatings. It should correspond to the Source No. on page 9. If applicable, it should also correspond to previously reported sources in "Air Pollution Emissions Report" (Form 150-R75).

[**] Adhesive type, pigment coating, barrier coating, polymeric coating, inorganic coating, etc. (specify).

[#] Branched alcohol, linear alcohol, ethyl acetate, toluene, xylene, ethers, MEK, naphtha, other (specify).

V MANUFACTURING INDUSTRIES

1) Brief Description of Process ____________________

Source No.	Process or operation using organic materials**	Type of material processed †	Annual thruput at source	Type †† and % of solvent in material		Quantity of volatile solvent lost to atmosphere during process lbs/yr.	Method used to determine emissions (guess or material balance)

2) Please complete Section VI, page 9 ; use same Source No.

[*] A source is an individual or similar pieces of equipment processing organic materials. It should correspond to the Source No. on page 9. If applicable, it should also correspond to previously reported sources in "Air Pollution Emissions Report" (Form 150-875).

[**] Dryer, reactor, mixing tank, etc.

[†] Paint, varnish, shellac, lacquer, enamel, primer, adhesive, ink, other (specify)

[††] Acetone, MEK, butyl acetate, cellosolve, ethanol, naphtha, toluene, mineral spirits, other (specify)

VI. CONTROL AND STACK INFORMATION

Instructions:

(1) A number should be assigned to each piece of equipment that emits hydrocarbons or to a number of similar units that are vented to a common stack. The Source No. below should correspond to the sections previously filled out. If similar equipment have different control equipment please split the source number to a, b or c.

(2) Identify the process or operation from which hydrocarbons are emitted. For example, dry cleaner, degreasing tank, spray booth, reactor, etc. If more than one unit is emitting to a common stack, specify the number of units.

(3) Identify the hydrocarbon control method used such as after-burners, scrubbers, carbon adsorption, condensers, etc.

(4) Indicate approximate efficiency if known.

(5) Indicate installation date of control equipment.

(6) If hydrocarbons are emitted from a stack, provide height, diameter, temperature, velocity and flow rate information in appropriate columns.

	(1)	(2)	(3)	(4)	(5)	(6)				
						Stack Data				
	Source No.	Process or Operation	Hydrocarbon Control Equipment	Efficiency of Control Equipment	Date of Instal-lation	Height (ft)	Inside Dia. (ft)	Temp. (°F)	Velocity (feet per sec)	Flow rate (ft³/min)
EXAMPLE	99	Paint Mixing Tank	Adsorber	90%	1969	20	1.5	77	20	2100

(7) PLEASE complete the last sections on page 10.

VII. BULK SOLVENT STORAGE

A. Please complete the following information for each storage tank greater than 250 gallons capacity.

Tank No.	Solvent Type	Capacity	Annual Thruput	Type of Fill and Control Equipment*

VIII. EFFECTS OF ENERGY CRISIS

Please state the changes in type and estimated annual consumption of solvent as a result of the energy crisis.

---

* Submerged fill, splash fill, return vent line, adsorber

Table A-2. STUDY AREA BULK STORAGE INFORMATION

1. Company name: ______________________________
2. Tank location: (name a few nearby cross streets to aid us in locating your facilities on our maps) ______________________________
   ____
3. Person completing form: ____________________ Title: ______________
4. Phone number: ________________
5. Type of products stored: ______________________________
   ____
6. Specify number of fixed-roof tanks at this facility: ______________
7. Specify number of floating-roof tanks at this facility: ______________
8. Please use the following space to include any information that would aid us in obtaining accurate emission estimates: ______________________________
   ____
   ____
   ____
   ____
   ____
   ____

Table A-2 (continued). STUDY AREA BULK STORAGE INFORMATION

1. Tank location (if available a diagram of area should be supplied.) ________
____
2. Tank Identification (number or name) ________________
3. Tank capacity, gals. ____________
4. Tank dimensions, ft.
   a) Diameter ____ b) Height ____ c) Length ____ d) Width ____
5. Tank shape. Cyclindrical ____ Spherical ____ Other describe ____________
6. Tank material of construction. Steel ___ Fiberglass ___ Other describe ________
7. Paint on tank roof.
   a) White ____ b) Aluminum ____ c) Light Grey ____ d) Medium Grey ____
   e) Other describe ________________________
8. Paint on shell
   a) White ____ b) Aluminum ____ c) Light Grey ____ d) Medium Grey ____
   e) Other describe ________________________
9. Tank condition. Good ____ Fair ____ Poor ____
10. Average vapor space height, ft. __________
11. Type of tank (check all applicable).
    a) Fixed Roof ____ b) Floating Roof ____ c) Variable Vapor Space (indicate expansion capacity) ________ d) Pressure ____ e) Underground ____
    f) Aboveground ____
12. If tank is floating roof.
    Type of roof: Double Deck ____ Pontoon ____ Other describe ____________
    Type of seal: Single ____ Double ____ Other describe ____________
    Type of construction: Riveted ____ Welded ____ Other describe ____________
13. Chemical name of liquid being stored. ________________
14. True vapor pressure of liquid __________ psia at ________ °F.
15. Density of liquid at storage temperature (lbs per gal) ____________
16. Average molecular weight of liquid (lbs per mole) ____________
17. Throughput for the year 1973 ________________(gals per year)
18. On a seperate sheet please describe any future anticipated storage tanks.
19. Type of loading: vessel___, barge___, truck___(check)
20. Type of filling: submerged___, splash___

Name: ____________________ Date: ____________________

Title: ____________________ Phone: ____________________

APPENDIX B

LABEL AND WORK SHEET COMPUTER PROGRAM

```
      DIMENSION  A(45),C(4,26),ZIP(5),SIC(4),PLT(4),NCT(52)
      REAL NAME(54,15)
      DATA CC,BB/',',' '/
C     READS CITIES
      DO 211 J=1,54
211   READ(5,101)    NCT(J),  (NAME(J,I),I=1,15)
 101  FORMAT(I4,2X,15A1)
      WRITE(6,650)
 299  JCOUNT=1
 300  DO 210 J=1,4
      DO 210 K=1,26
 210  C(J,K)= BB
C     READS SOURCE CARD
      READ(5,100,END=330)PLT,ICT,SIC,A, ZIP
C     SIC + PLT ID TO MATRIX
      DO 212 K=1,4
      C(1,K) = SIC(K)
 212  C(1,22+K) = PLT(K)
      J=2
      K=1
C     NAME + STREET TO MATRIX
      DO 200  I=1,45
      IF(A(I).EQ.CC) GO TO 39
      IF(K.LT.21) C(J,K) = A(I)
      K=K+1
      GO TO 200
  39  C(J,K) = CC
      J=J+1
      IF(J.EQ.4) GO TO 215
      K=1
 200  CONTINUE
C     CITY + ZIP TO MATRIX
C     CHECKS LIST FOR CITY
 215  DO 216 I=1,54
      IF(ICT.EQ.NCT(I)) GOTO 220
 216  CONTINUE
 220  DO 221 K=1,15
      IF(K.GT.10) C(4,K+11) = ZIP(K-10)
 221  C(4,K)=NAME(I,K)
      WRITE(6,550) ((C(L,M), M=1,26), L=1,3),(C(4,M),M=1,15),(C(4,M),
     * M=22,26)
 550  FORMAT(/// 1X,36(1H-),5('+',10(1H-)),'+',25(1H-)/3X,26A1,8X,6('+',
     *10X) /3X,26A1,8X,6('+',10X) /3X,26A1,8X,6('+',10X) /3X,15A1,6H R.I
     *. ,5A1,8X,6('+',10X))
      WRITE(1,250) ((( C(L,M),M=1,26),L=1,3),(C(4,M),M=1,15),(C(4,M),M=
     *22,26),MI=1,2)
 250  FORMAT ( //3X,26A1/3X,26A1/3X,26A1/3X,15A1,6H R.I. ,5A1)
      JCOUNT= JCOUNT + 1
      IF (JCOUNT.LE.7) GO TO 300
      WRITE(6,650)
 650  FORMAT('1',36X,' TEL NO ',3X,' DATE Q IN ',3(1X,' TEL CONT '),3X,
     *'COMMENTS' )
      GO TO 299
 330  STOP
 100  FORMAT(5X,4A1,1X,I4,1X,4A1,45A1,5A1)
      STOP
      END
```

Table A-1. QUESTIONNAIRE TO MANUFACTURING INDUSTRIES AND DRY CLEANERS

official use
Rec. by__________ Date:______
SIC______________________
X,Y______________________

I. GENERAL INFORMATION

A. Company Name____
Plant Address________________________City______________Zip Code______
Nearest Street Intersection__________________________________
Mailing Address______________________City______________Zip Code______

B. Person to contact about form______________________________
Telephone_________________________Title______________________

C. Approximate number of employees______________

D. Nature of Business____
____

E. Normal Operating schedule
__________Hrs./day__________days/wk.__________wks/yr.

F. Approximate Percent Seasonal Operation:

Dec.-Feb.	Mar-May	Jun-Aug	Sept.-Nov.

G. Are volatile organic or solvent-containing materials such as cleaning fluids, coatings, adhesives, inks, etc. used in your operation? ____ Yes ____ No

If NO, sign form and return

If YES, sign form and complete only the sections pertaining to your operation:

	Page
II. Dry Cleaning	2, 9 & 10
III. Degreasing	3, 9 & 10
IV. Surface Coating Applications	
A. Fabric and Rubberized	4, 9 & 10
B. Protective or Decorative other than IV-A	5, 9 & 10
C. Printing	6, 9 & 10
D. Miscellaneous Surface Coatings (Adhesives, Paper, Leather, films, Glass etc)	7, 9 & 10
V. Manufacturing Industries	8, 9 & 10

Signature ______________________ Date ____________________

II. DRY CLEANING

A. Amount of clothes cleaned per year ________________ tons.

B. Type of dry cleaning unit ☐ hot or dry-to-dry
☐ cold or transfer

C. Type and amount of solvent cleaner purchased in 1973.

Perchloroethylene ____________________________ Gal./Yr.
Stoddard solvent _____ ____________________ Gal./Yr.
Other (specify) ____________________________ Gal./Yr.
Other (specify) ____________________________ Gal./Yr.

D. Supplier of solvent - Name and address

Perchlorethylene ____
____

Stoddard Solvent ____
____

Other (specify) ____
____

Other (specify) ____
____

E. Please complete Section VI, page 9.

If you have any questions about this section please contact:

Mr. Roger Schilling
Field Representative for
International Fabricare Institute
5 Shawsheen Ave.
Bedford, Mass.
(617) 275-7583

III. DEGREASING OPERATIONS

A. Type of degreasing: ☐ cold solvent cleaning
☐ vapor degreasing

B. Type and amount of solvent purchased for degreasing operations.

1) Stoddard ____________________ Gal./yr.
2) 1,1,1-Trichloroethane (Chlorothene VG) ____________________ Gal./yr.
3) Perchloroethylene ____________________ Gal./yr.
4) Methylene chloride ____________________ Gal./yr.
5) Trichloroethylene ____________________ Gal./yr.
6) Other (specify) ____________________ Gal./yr.
7) Other (specify) ____________________ Gal./yr.

C. Suppliers of Solvents
____
____

____
____

____
____

D. Waste solvent disposal method
____

E. Amount of each solvent returned for reprocessing to vendor or collector

1) Stoddard ____________________ Gal./yr.
2) Trichloroethane ____________________ Gal./yr.
3) Perchloroethylene ____________________ Gal./yr.
4) Methylene chloride ____________________ Gal./yr.
5) Trichloroethylene ____________________ Gal./yr.
6) Other (specify) ____________________ Gal./yr.
7) Other (specify) ____________________ Gal./yr.

F. Please complete Section VI, page 9.

IV-A. FABRIC OR RUBBERIZED COATING APPLICATION

(1) Material(s) being coated ____________________.

(2) Type of coating process:

Source No.*	State Coating Process: Impregnation, "Wet" Coating, Hot Melt Coating, Lamination	Type of Coating**	Amount of Coating (Gal/Yr)	Type† and % of Vehicle Solvent		Type† and Amount of Solvent Added to Coating (Gal/Yr)	

(3) Type† of cleaning solvent ____________________, Amount ____________ (Gal/Yr)

____________________, Amount ____________ (Gal/Yr)

(4) Is any solvent returned to supplier or collector?

_____No _____Yes Type†____________, Amount __________ (Gal/Yr)

(5) Please complete Section VI, p. 9; use same Source No.

---

*A source is an individual or similar pieces of equipment such as coaters, dryers, etc. It should correspond to the Source No. on page 9. If applicable, it should also correspond to previously reported sources in "Air Pollution Emissions Report" (Form 158-R75)

**Polyvinyl chloride, polyurethanes, etc.

†Toluene, naphtha, mineral spirits, MEK, xylene, chlorinated hydrocarbon, other (specify).

IV-5. PROTECTIVE OR DECORATIVE COATINGS OTHER THAN FABRIC COATING

1. Indicate material being coated ____
____

2. Type and amount of coating used:

Source* Number	State Application Method: Spraying, Dipping, Roller, Flow, etc.	Type of Paint**	Amount Gals./yr.	% solids	Type† and % of major solvents	

3. Type† and amount of thinner used for dilution and cleaning not included above
________________________, Amount________________Gal./yr.
________________________, Amount________________Gal./yr.

4. Please complete Section VI, page 9.

---

*A source is an individual or similar pieces of equipment such as spray booths, tanks, dryers, etc. It should correspond to the Source No. on page 9. If applicable, it should also correspond to previously reported sources in "Air Pollution Emissions report" (Form 158-R75)

**(1) paint, (3) varnish/shellac, (4) lacquer, (5) enamel, (6) primer

†If known, - acetone, isopropyl alcohol, MEK, butyl acetate, cellusolve, toluene, etc.

IV-C. PRINTING

(1) Material being coated ______________________________.

(2) Type of printing process:

Source No.[*]	State Printing Process: Letterpress, Flexographic, Lithographic, Gravure, Screen	Type of Ink[**]	Amount (lb/yr)	Type[#] and % of major solvents in ink	

(3) Type[#] and amount of solvent used for dilution and cleaning not included above: ________________ Amount __________ Gal./yr.

________________ Amount __________ Gal./yr.

(4) Please complete Section VI p. 9 ; ; use same Source No.

---

[*] A source is an individual or similar printing machines, dryers, etc. It should correspond to the Source No. on page 9. If applicable, it should also correspond to previously reported sources in "Air Pollution Emissions Report" (Form 158-R75).

[**] Solvent based, oil based, lacquer-type, etc.

[#] Isopropyl alcohol, Ethanol, Propanol, Naphtha/Mineral Spirits, Toluene, MEK, other (specify)

IV-D. MISCELLANEOUS SURFACE COATING APPLICATION
(Adhesives, Paper, Leather, Films, Glass, etc)

(1) Material(s) being coated ______________________________

(2) Type of coating process:

Source No.[*]	State Coating Process: Spray, Flow, Dip, Roller, Brush, etc.	Type of Coating[**]	Amount of Coating (Gal/Yr)	Type[#] and % of Major Solvents in Coating	

(3) Type[#] and additional amount of solvent used for dilution and cleaning not included above ______________, Amount ____________ Gal/Yr.
______________, Amount ____________ Gal/Yr.

(4) Please complete Section VI, page 9 ; Use the same Source No.

[*] A source number is an individual or similar pieces of equipment using surface coatings. It should correspond to the Source No. on page 9. If applicable it should also correspond to previously reported sources in "Air Pollution Emissions Report" (Form 150-R75).

[**] Adhesive type, pigment coating, barrier coating, polymeric coating, inorganic coating, etc. (specify).

[#] Branched alcohol, linear alcohol, ethyl acetate, toluene, xylene, ethers, MEK, naphtha, other (specify).

V. MANUFACTURING INDUSTRIES

1) Brief Description of Process ______________________________

Source No.*	Process or operation using organic materials**	Type of material processed +	Annual thruput at source	Type ++ and % of solvent in material		Quantity of volatile solvent lost to atmosphere during process lbs/yr.	Method used to determine emissions (guess or material balance)

2) Please complete Section VI, page 9 ; use same Source No.

---

*A source is an individual or similar pieces of equipment processing organic materials. It should correspond to the Source No. on page 9. If applicable, it should also correspond to previously reported sources in "Air Pollution Emissions Report" (Form 158-R73).

**Dryer, reactor, mixing tank, etc.

+Paint, varnish, shellac, lacquer, enamel, primer, adhesive, ink, other (specify).

++Acetone, MEK, butyl acetate, cellosolve, ethanol, naphtha, toluene, mineral spirits, other (specify).

VI. CONTROL AND STACK INFORMATION

Instructions:

(1) A number should be assigned to each piece of equipment that emits hydrocarbons or to a number of similar units that are vented to a common stack. The Source No. below should correspond to the sections previously filled out. If similar equipment have different control equipment please split the source number to a, b or c.

(2) Identify the process or operation from which hydrocarbons are emitted. For example, dry cleaner, degreasing tank, spray booth, reactor, etc. If more than one unit is emitting to a common stack, specify the number of units.

(3) Identify the hydrocarbon control method used such as after-burners, scrubbers, carbon adsorption, condensers, etc.

(4) Indicate approximate efficiency if known.

(5) Indicate installation date of control equipment.

(6) If hydrocarbons are emitted from a stack, provide height, diameter, temperature, velocity and flow rate information in appropriate columns.

EXAMPLE

(1)	(2)	(3)	(4)	(5)	(6)				
					Stack Data				
Source No.	Process or Operation	Hydrocarbon Control Equipment	Efficiency of Control Equipment	Date of Installation	Height (ft)	Inside Dia. (ft)	Temp. (°F)	Velocity (feet per sec)	Flow rate (ft^3/min)
99	Paint Mixing Tank	Adsorber	80%	1969	20	1.5	77	20	2100

(7) PLEASE complete the last sections on page 10.

VII. BULK SOLVENT STORAGE

A. Please complete the following information for each storage tank greater than 250 gallons capacity.

Tank No.	Solvent Type	Capacity	Annual Thruput	Type of Fill and Control Equipment *

VIII. EFFECTS OF ENERGY CRISIS

Please state the changes in type and estimated annual consumption of solvent as a result of the energy crisis.

---

* Submerged fill, splash fill, return vent line, adsorber

Table A-2. STUDY AREA BULK STORAGE INFORMATION

1. Company name: ______________________________

2. Tank location: (name a few nearby cross streets to aid us in locating your facilities on our maps) ______________________________

____

3. Person completing form: ____________ Title: ____________

4. Phone number: ____________

5. Type of products stored: ______________________________

____

6. Specify number of fixed-roof tanks at this facility: ____________

7. Specify number of floating-roof tanks at this facility: ____________

8. Please use the following space to include any information that would aid us in obtaining accurate emission estimates: ______________________________

____

____

____

____

____

____

Table A-2 (continued). STUDY AREA BULK STORAGE INFORMATION

1. Tank location (if available a diagram of area should be supplied.) ________
____
2. Tank Identification (number or name) ____________________
3. Tank capacity, gals. ____________
4. Tank dimensions, ft.
   a) Diameter ____ b) Height ____ c) Length ____ d) Width ____
5. Tank shape. Cylindrical ___ Spherical ___ Other describe ____________
6. Tank material of construction. Steel ___ Fiberglass ___ Other describe ________
7. Paint on tank roof.
   a) White ___ b) Aluminum ___ c) Light Grey ___ d) Medium Grey ___
   e) Other describe ________________________________
8. Paint on shell
   a) White ___ b) Aluminum ___ c) Light Grey ___ d) Medium Grey ___
   e) Other describe ________________________________
9. Tank condition. Good ___ Fair ___ Poor ___
10. Average vapor space height, ft. __________
11. Type of tank (check all applicable).
   a) Fixed Roof ___ b) Floating Roof ___ c) Variable Vapor Space (indicate expansion capacity) ______ d) Pressure ___ e) Underground ___
   f) Aboveground ___
12. If tank is floating roof.
   Type of roof: Double Deck ___ Pontoon ___ Other describe ____________
   Type of seal: Single ___ Double ___ Other describe ____________
   Type of construction: Riveted ___ Welded ___ Other describe ____________
13. Chemical name of liquid being stored. ____________________
14. True vapor pressure of liquid ________ psia at ________ °F.
15. Density of liquid at storage temperature (lbs per gal) ____________
16. Average molecular weight of liquid (lbs per mole) ____________
17. Throughput for the year 1973 ____________________(gals per year)
18. On a seperate sheet please describe any future anticipated storage tanks.
19. Type of loading: vessel___, barge___, truck___(check)
20. Type of filling: submerged___, splash___

Name: ____________________ Date: ____________________

Title: ____________________ Phone: ____________________

APPENDIX B

LABEL AND WORK SHEET COMPUTER PROGRAM

```
LEVEL  21                    MAIN                 DATE = 74109          14/47/04

      DIMENSION  A(45),C(4,26),ZIP(5),S7C(4),PLT(4),NCT(52)
      REAL NAME(54,15)
      DATA CC,BB/',',' '/
C     READS CITIES
      DO 211 J=1,54
211   READ(5,101)    NCT(J),  (NAME(J,I),I=1,15)
 101  FORMAT(I4,2X,15A1)
      WRITE(6,650)
 299  JCOUNT=1
 300  DO 210 J=1,4
      DO 210 K=1,26
 210  C(J,K)= BB
C     READS SOURCE CARD
      READ(5,100,END=330)PLT,ICT,SIC,A, ZIP
C     SIC + PLT ID TO MATRIX
      DO 212 K=1,4
      C(1,K) = SIC(K)
 212  C(1,22+K) = PLT(K)
      J=2
      K=1
C     NAME + STREET TO MATRIX
      DO 200  I=1,45
      IF(A(I).EQ.CC) GO TO 39
      IF(K.LT.21) C(J,K) = A(I)
      K=K+1
      GO TO 200
 39   C(J,K) = CC
      J=J+1
      IF(J.EQ.4) GO TO 215
      K=1
 200  CONTINUE
C     CITY + ZIP TO MATRIX
C     CHECKS LIST FOR CITY
 215  DO 216 I=1,54
      IF(ICT.EQ.NCT(I)) GOTO 220
 216  CONTINUE
 220  DO 221 K=1,15
      IF(K.GT.10) C(4,K+11) = ZIP(K-10)
 221  C(4,K)=NAME(I,K)
      WRITE(6,550) ((C(L,M), M=1,26), L=1,3),(C(4,M),M=1,15),(C(4,M),
     * M=22,26)
 550  FORMAT(/// 1X,36(1H-),5('+',10(1H-)),'+',25(1H-)/3X,26A1,8X,6('+',
     *10X) /3X,26A1,8X,6('+',10X) /3X,26A1,8X,6('+',10X) /3X,15A1,6H R.I
     *. ,5A1,8X,6('+',10X))
      WRITE(1,250) ((( C(L,M),M=1,26),L=1,3),(C(4,M),M=1,15),(C(4,M),M=
     *22,26),MI=1,2)
 250  FORMAT ( //3X,26A1/3X,26A1/3X,26A1/3X,15A1,6H R.I. ,5A1)
      JCOUNT= JCOUNT + 1
      IF (JCOUNT.LE.7) GO TO 300
      WRITE(6,650)
 650  FORMAT('1',36X,' TEL NO ',3X,' DATE Q IN ',3(1X,' TEL CONT '),3X,
     *'COMMENTS' )
      GO TO 299
 330  STOP
100   FORMAT(5X,4A1,1X,I4,1X,4A1,45A1,5A1)
      STOP
      END
```

APPENDIX B

LABEL AND WORK SHEET COMPUTER PROGRAM

```
      DIMENSION  A(45),C(4,26),ZIP(5),SIC(4),PLT(4),NCT(52)
      REAL NAME(54,15)
      DATA CC,BB/',',' '/
C     READS CITIES
      DO 211 J=1,54
211   READ(5,101)    NCT(J),  (NAME(J,I),I=1,15)
 101  FORMAT(I4,2X,15A1)
      WRITE(6,650)
 299  JCOUNT=1
 300  DO 210 J=1,4
      DO 210 K=1,26
 210  C(J,K)= BB
C     READS SOURCE CARD
      READ(5,100,END=330)PLT,ICT,SIC,A, ZIP
C     SIC + PLT ID TO MATRIX
      DO 212 K=1,4
      C(1,K) = SIC(K)
 212  C(1,22+K) = PLT(K)
      J=2
      K=1
C     NAME + STREET TO MATRIX
      DO 200  I=1,45
      IF(A(I).EQ.CC) GO TO 39
      IF(K.LT.21) C(J,K) = A(I)
      K=K+1
      GO TO 200
  39  C(J,K) = CC
      J=J+1
      IF(J.EQ.4) GO TO 215
      K=1
 200  CONTINUE
C     CITY + ZIP TO MATRIX
C     CHECKS LIST FOR CITY
 215  DO 216 I=1,54
      IF(ICT.EQ.NCT(I)) GOTO 220
 216  CONTINUE
 220  DO 221 K=1,15
      IF(K.GT.10) C(4,K+11) = ZIP(K-10)
 221  C(4,K)=NAME(I,K)
      WRITE(6,550) ((C(L,M), M=1,26), L=1,3),(C(4,M),M=1,15),(C(4,M),
     * M=22,26)
 550  FORMAT(/// 1X,36(1H-),5('+',1C(1H-)),'+',25(1H-)/3X,26A1,8X,6('+',
     *10X) /3X,26A1,8X,6('+',10X) /3X,26A1.8X,6('+',10X) /3X,15A1,6H R.I
     *. ,5A1,8X,6('+',10X))
      WRITE(1,250) ((( C(L,M),M=1,26),L=1,3),(C(4,M),M=1,15),(C(4,M),M=
     *22,26),MI=1,2)
 250  FORMAT ( //3X,26A1/3X,26A1/3X,26A1/3X,15A1,6H R.I. ,5A1)
      JCOUNT= JCOUNT + 1
      IF (JCOUNT.LE.7) GO TO 3C0
      WRITE(6,650)
 650  FORMAT('1',36X,' TEL NO ',3X,' DATE Q IN ',3(1X,' TEL CONT '),3X,
     *'COMMENTS' )
      GO TO 299
 330  STOP
 100  FORMAT(5X,4A1,1X,I4,1X,4A1,45A1,5A1)
      STOP
      END
```

HEAT EMISSION METHODOLOGY

Emission or Data Conversion Factors

The derivation of emission estimates from continuously monitored operating variables is a critical step that will determine the validity of the high resolution inventory data. Emission factors as currently used in developing emission inventories are generalized factors that are most valid when applied to a large number of sources or processes especially over extended time periods. They have limited applicability for use with single sources, certainly in the estimation of hourly emissions, and cannot therefore be used indiscriminately in deriving an inventory for RAPS in the manner proposed. The whole point of this inventory is to have high precision in terms of space and time, and for this reason, the best possible conversion factors must be used to develop the emissions data from the monitored variables. In general, this means that specific factors must be developed on an individual basis for each source for which the critical relationships are not already known with a high degree of confidence. (Even in the latter cases, some testing and verification would be desirable.) On the other hand, such specific source testing is a costly and time-consuming activity to be performed only when necessary. It is recommended, therefore, that consideration be given to using published, established emission factors for each source, where the type of equipment or activity is sufficiently typical that the published emission factors can be identified as being truly representative of the case in question. It should be noted that, in general, the published factors have the most credibility for the major combustion sources (particularly in the case of SO_2 emissions). It is important to recognize, however, that in the case of the RAPS inventory, the role of minor sources is of great importance in local effect, i.e., at near-surface levels, with the spatial resolution required for RAPS. Lower confidence factors are assigned to emission factors for such lesser sources (quality factors B and lower in the categorization of Reference 11). Considerable caution must therefore be exercised in treating such lesser sources. This is especially the case for area sources, which, although minor contributors to the total burden, are important on the local scale. Special care is necessary to improve the accuracy of emission factors from such sources for use in refined modeling techniques.

AREA SOURCES

Area Sources

The methodologies for developing an hourly emission inventory for area sources are described in this section of the handbook. The first section contains the initial effort to develop a preliminary area source inventory which was more detailed than NEDS (1). The second section describes the technique used to develop the initial grid system for RAPS (2). The last six parts (3-8) describe the methodologies being developed for RAPS on the various area source categories.

1. Preliminary Information; Developed for this handbook by the National Air Data Branch, April 1975
2. Computer Assisted Area Source Emissions Gridding Procedure; Research Triangle Institute EPA-450/3-74-035, January 1974
3. Stationary Area Source Methodology; Environmental Science and Engineering, Preliminary Draft
4. Highway Area Source Methodology; Under development by Washington University
5. River Vessel Methodology; Department of Transportation, preliminary information.
6. Fugitive Dust Methodology; Under development by Midwest Research Institute
7. Airport Emission Methodology; GCA/Technology Division, December 1974, Contract No. 68-02-0041, Task 18
8. Off-Highway Mobile Sources Methodology; Southwest Research Institute, EPA-RTP/3-75-002, October 1974

1. Preliminary Information

The existing NEDS inventory for stationary area sources were apportioned to the grid system developed by Research Triangle Institute. They developed automatic apportioning factors that took the NEDS data on a county basis and apportioned it to the grid system. Examples of apportioning factors are housing units, population, inverse population density.

As of August 1, 1973, the following inventory data were available for review in Room 627A, Mutual Bldg., Durham, N.C. (FTS 919-686-8395) (Com. 919-688-8146, ext. 395).

1. A computer-drawn map depicting all of the grid squares for the AQCR scaled 1:250000
2. A computer deck (1,843 cards) of area source emissions (SO_2 and TSP) for the AQCR formated for input to the IPP model in tons/day.
3. A printer listing of the IPP input cards for the AQCR.
4. A computer listing and card deck of the description of each grid square including identification (sequence) number, UTM coordinated of lower left corner, area (Km), and political subdivision (county) to which the grid square is assigned.
5. A printer listing of the cards keypunched with the overriding apportioning weighting factors provided by EPA. These overriding factors were used for airports, railroads, and vessels. (Where a source category for an entire county was overridden, this was done by modifying the default weighting factor in the source program deck for that particular, i.e., no cards were keypunched.)
6. Computer printouts for each of the 12 political subdivisions (11 counties and City of St. Louis) with apportioned fuels (tons/yr) for all source categories (on Form EPA [DUR]219, 2/72) for the five pollutants, STP, SO_2, NO_x, HC and CO. These printouts also have for each county the total emissions which have been compared with the NEDS "USER'S FILE" output. Also, the total emissions by source-category pollutant combination is output and shows the contribution of each to the total.
7. The USGS topographic maps for the AQCR.
8. The population center compute plots for each of the 12 political subdivisions (counties).

9. The present NEDS point source inventory in IPP format.

The RAPS Data Manager, Robert Browning (Com. 919-549-8411, ext. 4545) also has the above items except number 7.

The initial grid system developed by RTI for St. Louis was not usable for the RAPS program because a large number of grids were 2.5 kilometers on a side and some of the diffusion models could not imput area source emission data on the basis of non-integer grid size.

The non-integer grids have been altered and for the AQCR there are now 1988 grids ranging from one to ten kilometers on a side. Available for review at the National Air Data Branch is the following:

1. A computer drawn map depicting all of the grid squares for AQCR #70 to be used in the RAPS emission inventory.
2. A computer listing with the description of each grid square including identification (sequence) number, and UTM coordinates zones 15 and 16.

EPA-450/3-74-035

COMPUTER ASSISTED AREA SOURCE EMISSIONS GRIDDING PROCEDURE (CAASE) USER'S MANUAL

by

Research Triangle Institute
Research Triangle Park, North Carolina 27709

Contract Number 68-02-1014

EPA Project Officer: Charles C. Masser

Prepared for

ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, N. C. 27711

January 1974

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This report is issued by the Environmental Protection Agency to report technical data of interest to a limited number of readers. Copies are available free of charge to Federal employees, current contractors and grantees, and nonprofit organizations - as supplies permit from the Air Pollution Technical Information Center, Environmental Protection Agency, Research Triangle Park, North Carolina 27711; or, for a fee, from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22151.

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The development of the CAASE system, and its application to fifteen (15) Air Quality Control Regions (AQCR's) thus far, has been largely a team effort with Dr. J. Hammerle and Mr. C. Masser of EPA/NADB contributing heavily to the development of the system.

The work has been conducted under the direction of Mr. Charles Masser, who is the EPA Project Officer for the contract.

RTI staff members principally participating in developing the system and applying it are as follow:

H. L. Hamilton, Laboratory Supervisor
R. C. Haws, Project Leader
R. E. Paddock, Systems Analyst
S. K. Burt, Programmer
M. F. Dworschak, Programmer
A. B. Murray, Programmer
P. B. Daniel, Secretary-Research Assistant.

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1.0 INTRODUCTION

1.1 Purpose

The National Air Data Branch of EPA has the responsibility for developing an accurate emissions inventory for all designated pollutants for the entire United States. The emissions inventory data must be in a format suitable for use as input to existing computer programs for displaying air quality, or for evaluating State Implementation Plans. Key computer programs which require emissions inventory data are the Air Quality Display Model (AQDM) and the Implementation Planning Program (IPP).

Point Sources of emissions present no difficulties with regard to the formatting of data for use with AQDM or IPP. Area source emission data, however, present problems. Usually, the smallest geographic unit for which accurate primary data (e.g. annual residential fuel consumption) are available is the county. These data must be disaggregated and appropriately allocated (as emissions) to smaller areas to provide an adequately detailed input for AQDM or IPP.

The CAASE programs (CAASE1 through CAASE5) with associated subroutines and off-line procedures provide an objective method for allocating county-level data to grid squares selected on the basis of demographic features and sized to give appropriate detail for input to air quality modeling programs. CAASE is an acronym made up of the first letters of Computer Assisted Area Source Emissions gridding.

1.2 General Background

The attainment of acceptable air quality within an Air Quality Control Region requires the implementation of appropriate strategies for the control of emissions of pollutants from individual sources or classes of sources. The probable success of candidate control strategies can be evaluated through the use of computer simulation models. These models manipulate the characteristics of the many sources, e.g. location, annual emissions, height and temperature of emissions, and meteorological conditions, e.g. wind direction and speed distribution with associated thermal stability conditions, to produce a distribution of ambient air pollutant concentrations over the region being considered.

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Simulation models frequently used are based on Gaussian plume formations and accept as inputs either point sources, or area sources (which are converted to virtual point sources). Point sources are those individually identifiable boiler stacks, process vents, etc., emitting more than some arbitrarily specified mass of pollutant each year. Area sources, however, include the more ubiquitous, individually small sources which cannot be specifically located.

The objective of the CAASE method is the improvement of the characterization of area sources. Basic data for the determination of area source emissions seldom, if ever, are available for geographic or political units or areas smaller than the county, or in some cases, the large city which functions politically independently of the surrounding county. These basic data are in the form of, for example, annual fuel consumption, by fuel type, for residential, for commercial and institutional, and for industrial heating; acreage burned by forest fires; landing-takeoff cycles for military, for commercial and for civil aircraft; gasoline or diesel fuel consumed by light, heavy and off-highway vehicles, or vehicle miles traveled by road classification; etc. These data can be converted to pollutant emissions by the application of appropriate emission factors.

The geographic size of a county, however, is too large for practical use in simulation models for AQCR's. Logical procedures are required for distributing the county totals basic data or derived emissions data to smaller areas. Further constraints imposed by the simulation models require that these small areas be squares, although they need not be of uniform size. Various criteria have been proposed as bases for selecting the sizes and distribution of the emission area squares. Urbanization, land use, housing counts, and population have all been used subjectively to grid AQCR's into emission area squares (hereafter called grid squares) and subsequently to apportion county totals of pollutant emissions into each grid square. In general, the philosophy followed has required that urbanized or industrialized portions of the county or AQCR be gridded into small squares to provide for detailed representation of concentration of pollution sources. Conversely, rural areas with few pollution sources are adequately represented by large grid squares. Essentially, application of this philosophy results in apportioning county total emissions to grid squares according to subjective estimates of the distribution of population. Since air pollution derives from human activity this procedure provides a reasonable approach to developing area source emission distributions.

The development of the CAASE programs began as an effort to reduce the subjectivity inherent in distributing population into pre-selected grid squares. Success in this effort would concurrently reduce the time and effort required to complete the area source emission distribution.

The Bureau of the Census of the U.S. Department of Commerce has prepared a modified Master Enumeration District List (MEDList) which includes, in addition to the district identification, population count, housing count, etc., the geographic coordinates of the center of area of each of the enumeration districts. A computer plot of these population centers, coded to graphically represent population count used in conjunction with U.S. Geological Survey maps providing topographic and terrain features, furnishes a relatively detailed information base for constructing a county grid square system.

The procedures described in this manual have evolved from a feasibility study (Contract CPA 70-147) in which three AQCR's, 145 (Lancaster, Gage, and Jefferson Counties, Nebraska), 99 (South Central Kansas), and 130 (Metropolitan Fargo-Moorehead) were gridded. In this study the ambient air quality indicated by the AQDM simulation model, based on a previously prepared (by another EPA contractor) area source emissions grid and a corresponding simulation based on the CAASE grid were compared. Because smaller grid squares were used by the CAASE method for central urban areas — where the plotted population data showed concentrations of people — higher peak values of ambient pollutant concentrations were shown for the cities, and sharper gradients of pollutant concentrations appeared in the urban to rural transition zone. rural areas ambient pollutant concentrations did not differ with the change in the grid system.

Subsequent to the demonstration of feasibility of the CAASE method, fifteen AQCR's have been gridded and area source emissions have been determined for each grid square (Contract 68-02-1014). From this experience, the CAASE method as described in this manual has evolved.

1.3 The CAASE Method

CAASE has five computer programs associated with it and various subroutines called by these programs. Off-line gridding is done in the procedure steps between the execution of the second and third programs. For convenience the programs have been numbered CAASE 1 through CAASE 5 and they perform the following functions:

CAASE1 strips the MED-X* census tape files for all of the enumeration district population entries for all counties in the Air Quality Control Region (AQCR) being processed. CAASE1 also converts the coordinates of the center of each enumeration district from latitude and longitude (in degrees) to Universal Transverse Mercator (UTM) coordinates which are used in dispersion modeling programs. CAASE1 also writes tape files to be used as input to the CAASE2 and the CAASE4 programs.

The CAASE2 program, using edited tape files written by CAASE1 and a line-drawing plotter (in this application a CALCOMP plotter), plots circles with their radii proportional to the population counts. A circle is plotted for each enumeration district with its center at the geographical center of the enumeration district. This plotted output can then be overlayed onto the standard USGS map(s). The maps and scaling used have been the USGS 1:250,000 with a 1-inch radius representing 4,000 people. CAASE2 plots a separate chart (map) for each county in the AQCR. This procedure is used because the primary purpose of the gridding is to select grid squares within a county so that total emissions (or total fuels) for the county can be apportioned into these grid squares. When all counties for a particular AQCR have been processed through CAASE1 and CAASE2, a grid for the entire AQCR must be determined using partly subjective means (see Section 8). In order to make this determination a

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*Master Enumeration District Listing extended with geographic coordinates (MED-X).

light-table is used and the population plots are overlayed onto a USGS map(s) containing all counties for the AQCR. A grid is selected for the entire AQCR with each grid square having a side length which can range from 1 km to 30 km. Any size could be selected, but it is generally agreed that this is the range which will best depict the area source inputs for dispersion modeling, i.e. it provides enough resolution, but does not generate more resolution than the models warrant (which would result in a waste of computer time when dispersion modeling programs are run). Because determining the sizes of the grid squares and where they should be placed is partially subjective, the technical personnel performing this step should have had some experience in gridding area source emissions using other techniques or should have been trained to use this technique. That is to say, the CAASE1 and CAASE2 programs have simply produced, in graphical form, a representation of where the people are located within the counties.

After all grid squares have been constructed for the entire AQCR being processed, a card deck is prepared describing this grid for input to the CAASE3 program. Specifically, the grid squares are numbered in some orderly way, preferably sequentially by county. A load sheet is then prepared for keypunching a card associated with each grid square. On this load sheet the grid identification number (ID), the UTM coordinates of the lower left-hand corner of the grid square, and the side length of the square are entered. The county, state, and AQCR are also entered for identification purposes. It is very easy, during this step, to introduce clerical errors in the recording of coordinates and side lengths. However, the CAASE3 program offers an opportunity to find keypunch errors not discovered while verifying.

The CAASE3 program uses the input grid description cards and draws, to scale, a map of the entire AQCR. The map drawn by CAASE3 portrays the grid, and it is helpful in isolating any errors which may have been introduced when preparing the load sheets or in keypunching and verifying the cards. All grid elements must be square and errors of omission or the incorrect recording of a coordinate(s) are quite obvious when this map is visually checked. A symbol, in this application an "X," is optionally plotted at the center of each grid square to help in the location of errors.

After the grid description cards have been corrected, if necessary, for any errors found by using the CAASE3 program, the next step in the procedure is to use the CAASE4 program which assigns apportioning values to each of the grid squares. For each area source emission category included on the area source input form (EPA (DUR) 219 3/72), an apportioning factor has been assigned using objective data when possible. Bureau of the Census MED-X data tapes contain a population count, a housing count, and a rural/urban classification for each enumeration district. Each grid description card includes the side length of the grid square from which the area is calculated. County totals for most of the area source emissions categories can be objectively apportioned using population, housing, area, or a combination of these three measurements. One obvious exception is the apportioning of emissions from aircraft operations which would require a knowledge of airport locations and, if more than one airport was located within a county, their relative operations activity.

The CAASE4 program logic has been written to permit the user to subjectively override any of the objective apportioning factors. The actual apportioning factor for each source category used within the program, is the product of a weighting factor and the assigned objective factor. This allows the user to override the programmed (or objective) apportioning factor within any particular county (or counties) if information to do so is available. The output of the CAASE4 program includes binary tape files which are used as input files to the CAASE5 program. CAASE4 output files contain, for each grid square and source category combination for each county, a number which can be used to apportion a fraction of the county total into each grid square within the county. Each county within the AQCR is processed separately through the CAASE4 program using the grid squares associated with the county, the MED-X census data and any overriding weighting factors provided as additional input data.

The CAASE5 program, using "fuel" totals for each of the emission source categories for area sources, apportions these "fuels" into the individual grid squares. CAASE5 uses the same methods as those used in the EPA program NEO3 to calculate the emissions using fuel totals and emission factors for each of the source emissions categories. The term "SMEAR" has generally been used when describing the process of apportioning the total emissions for a county into the grid squares within a county. The CAASE5 program does the "SMEARING" by using apportioning factors assigned by CAASE4. CAASE5 first "SMEARS" the "fuel" for each of the categories into each of the grid squares and outputs (prints) a tabular listing (and writes a binary magnetic tape) for all grid squares within the county for each emissions source category. For each area source emissions category, each grid square receives a fraction of the county total — that fraction being the number associated with that particular grid square and "fuel" category divided by the sum of all apportioning numbers for that "fuel" category within the county. For any area source category, the apportioning fractions summed over all grid squares for that county equals unity.

Procedurely, the pollutant emissions are calculated for the county totals and then "SMEARED." This procedure is used, rather than calculating emissions for each grid square using "SMEARED" fuels, because the calculations for "SMEARING" do not require as much computer time as the calculations of the emissions. For each source category, emissions are calculated for the five pollutants: suspended particles (SP), sulfur dioxide (SO_2), oxides of nitrogen (NO_x), hydrocarbons (HC), and carbon monoxide (CO). As emissions of each pollutant are calculated and "SMEARED," a tabular listing is output (printed) of the "SMEARED" emissions for each pollutant as was done with the fuels. The county totals for each emissions source category are output to indicate the contribution of each of them to the total emissions for each pollutant. For each grid square the "SMEARED" emissions from all source categories are summed for each pollutant for output in the Implementation Planning Program (IPP) expanded card format for area source inputs. A binary magnetic tape is also written containing all data items in the tabular listings and card decks. The output from CAASE5, then, includes tables of "SMEARED" fuel totals and "SMEARED" emissions for each of the five pollutants of interest, where for each grid square a separate value is printed for each source category. Also, a card deck is punched in the IPP format, containing, for each grid square, the total suspended particles, sulfur dioxide, oxides of nitrogen, hydrocarbon, and carbon monoxide emissions "SMEARED" into each grid square for all source categories. At the request of EPA the IPP input card format was expanded to include all five pollutants and the state and county code numbers. The county totals for each of the five pollutants are also printed and were used during the development and application of the CAASE method to compare CAASE program outputs with the total emissions for each county which were calculated by the EPA program NE03. A detailed description of each of these five main CAASE programs, their subroutines, the off-line gridding procedure, and the use of overriding apportioning factors, are contained in other sections of this manual.

Figure 1 is a flow chart of the overall CAASE system.

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CAASE SYSTEM DESCRIPTION

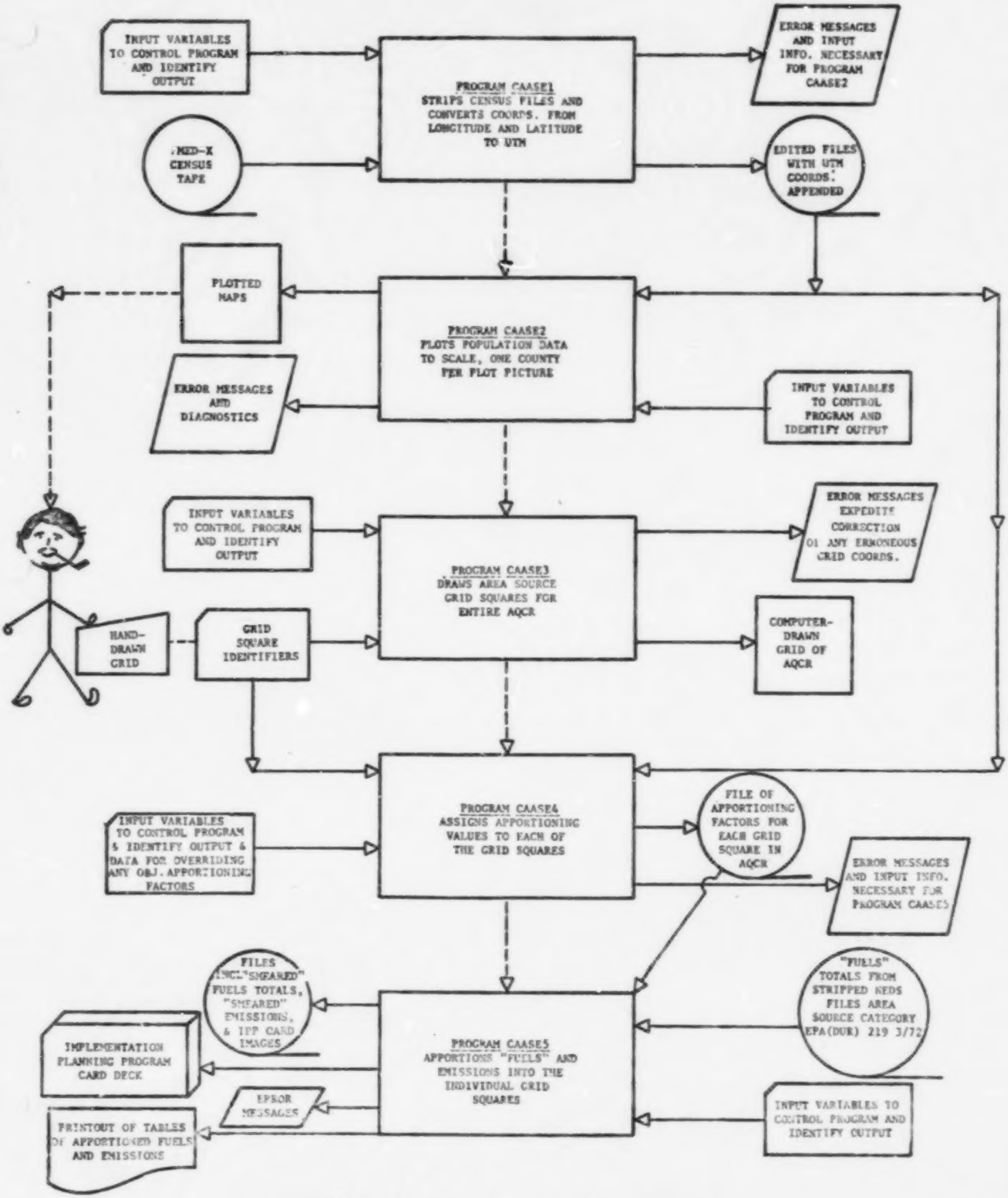

INPUT VARIABLES TO CONTROL PROGRAM AND IDENTIFY OUTPUT
PROGRAM CAASE1
STRIPS CENSUS FILES AND CONVERTS COORDS. FROM LONGITUDE AND LATITUDE TO UTM
ERROR MESSAGES AND INPUT INFO. NECESSARY FOR PROGRAM CAASE2
MED-X CENSUS TAPE
EDITED FILES WITH UTM COORDS. APPENDED
PLOTTED MAPS
PROGRAM CAASE2
PLOTS POPULATION DATA TO SCALE, ONE COUNTY PER PLOT PICTURE
ERROR MESSAGES AND DIAGNOSTICS
INPUT VARIABLES TO CONTROL PROGRAM AND IDENTIFY OUTPUT
INPUT VARIABLES TO CONTROL PROGRAM AND IDENTIFY OUTPUT
ERROR MESSAGES EXPEDITE CORRECTION OF ANY ERRONEOUS GRID COORDS.
PROGRAM CAASE3
DRAWS AREA SOURCE GRID SQUARES FOR ENTIRE AQCR
HAND-DRAWN GRID
GRID SQUARE IDENTIFIERS
COMPUTER-DRAWN GRID OF AQCR
PROGRAM CAASE4
ASSIGNS APPORTIONING VALUES TO EACH OF THE GRID SQUARES
INPUT VARIABLES TO CONTROL PROGRAM & IDENTIFY OUTPUT & DATA FOR OVERRIDING ANY OBJ. APPORTIONING FACTORS
FILE OF APPORTIONING FACTORS FOR EACH GRID SQUARE IN AQCR
ERROR MESSAGES AND INPUT INFO. NECESSARY FOR PROGRAM CAASE5
FILES INCL."SMEARED" FUELS TOTALS, "SMEARED" EMISSIONS, & IPP CARD IMAGES
"FUELS" TOTALS FROM STRIPPED NEDS FILES AREA SOURCE CATEGORY EPA(DUR) 219 3/72
IMPLEMENTATION PLANNING PROGRAM CARD DECK
PROGRAM CAASE5
APPORTIONS "FUELS" AND EMISSIONS INTO THE INDIVIDUAL GRID SQUARES
ERROR MESSAGES
PRINTOUT OF TABLES OF APPORTIONED FUELS AND EMISSIONS
INPUT VARIABLES TO CONTROL PROGRAM AND IDENTIFY OUTPUT

Figure 1. Flowchart of CAASE System

2.0 CAASE1 PROGRAM

2.1 Program Description

This program performs several functions which include the editing, conversion of coordinates (from geographic latitude and longitude to the universal transverse mercator (UTM) system), flags those counties which cross (straddle) two UTM zones, and calculates the length of the X and Y axes necessary for the subsequent plotting of the population at enumeration district centers. The program will process one or several counties contained in one or more states making up an Air Quality Control Region. Because the counties are dealt with in later programs as separate entities, CAASE1 generates a separate file for each county. The program uses two types of input data, (1) the Bureau of the Census MED-X data tape (MEDList with latitudinal and longitudinal coordinates added), and (2) punched cards to specify the values of variables for the county (or counties) being processed. Outputs include an edited, or stripped, file for each county, diagnostic messages, error messages when necessary, and information to aid in the execution of the next program in the series. In addition to systems subprograms, the subroutine CED009, described in Section 7.1 is used for converting coordinates. A logical flow chart describing CAASE1 is included in Appendix A.

2.2 Job Control Language (JCL) and Deck Setup

An example of a deck setup configuration is illustrated in Figure 2. Using the Parkersburg-Marietta AQCR as an example, the associated JCL and input data cards are illustrated in Figure 3. The JCL cards illustrated assume the following:

a. The program is in object deck form.

b. The punched cards assigning values to the variables are in the input job stream.

c. The MED-X census data are on magnetic tape.

d. The number of counties to be processed is nine and are located in two states (Ohio and West Virginia).

e. The output of census data is on magnetic tape with a separate file created for each county.

2.3 Input Information

A description of the punched card input variables appears in Table 1. It includes the scaling factor, the name of the selected Air Quality Control Region, the number of states in the AQCR, the name of each state, the number of counties in each state, the Federal county code number, and the name of each county. The scaling factor, which has the same value as one which will be used in the plotting of the population centers in CAASE2, is used with the differences between the minimum and maximum UTM coordinates of the easting and northing for UTM zone(s) associated with the county being processed to calculate the size of the plot "picture" needed. The scaling factor, although variable, has been calculated for a scale of 1:250,000 for all processing done in the applications thus far using the CAASE method. The input card layout is described in Table 2.

2.4 Output Information

Printed output from the program includes the Air Quality Control Region, state(s), and county(ies) being processed. Also output for each UTM zone in the county (most counties include only one zone), is the zone number, the minimum and maximum easting and northing UTM coordinate, and the minimum X axis and Y axis (in inches, using the scale factor (SCALEX) that was read in), necessary to portray all population centers on a computer drawn map. When all records for a county of interest have been processed, the county name, its number, and the number of records written on the output tape are printed. A magnetic tape is written with a separate file created for each county processed. Once the county of interest is found on the MED-X tape, a record is written for each input record except for the population data summary. The summarization of enumeration district population counts can be recognized by the program because the latitudinal and longitudinal coordinates are zero. Error messages are printed and, if they are fatal, the program operation is terminated. The census data record written by CAASE1 is essentially the same as the MED-X input record with the UTM zone number and the easting and northing UTM coordinates for each population center appended. Figure 4 is an example of a printout from CAASE1.

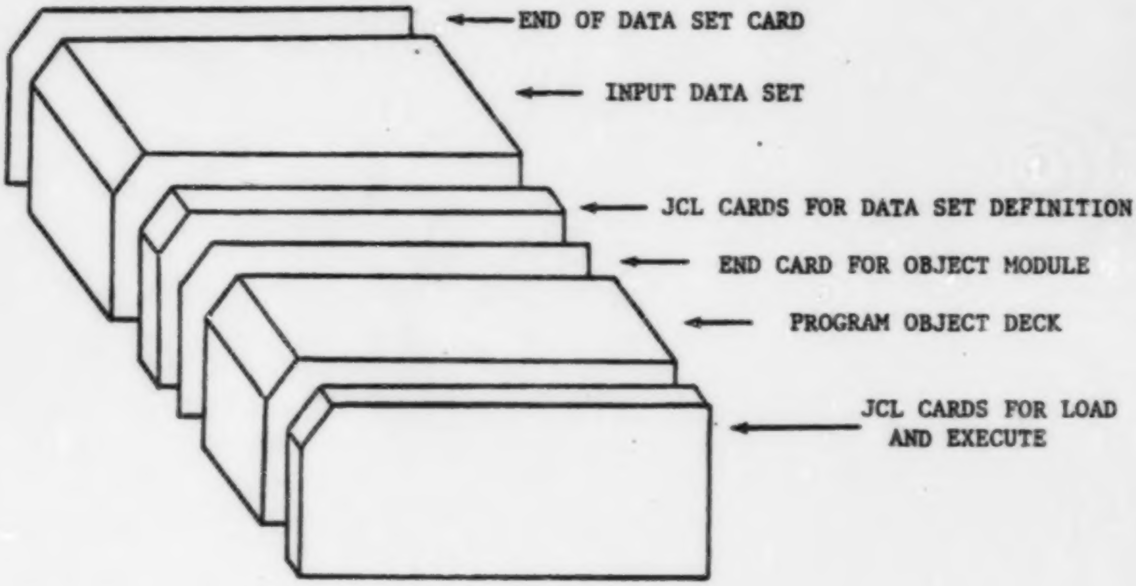
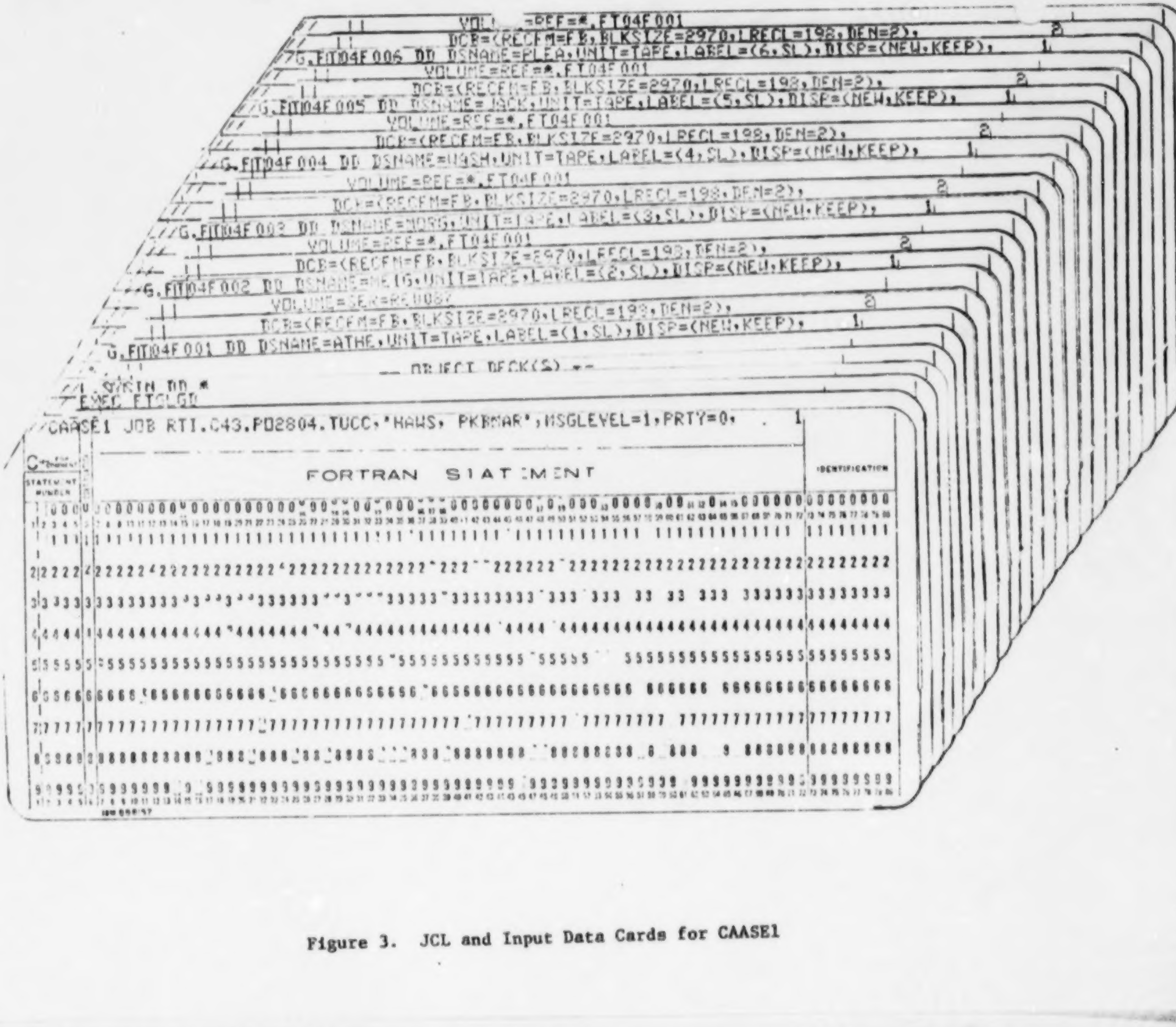

END OF DATA SET CARD
INPUT DATA SET
JCL CARDS FOR DATA SET DEFINITION
END CARD FOR OBJECT MODULE
PROGRAM OBJECT DECK
JCL CARDS FOR LOAD AND EXECUTE

Figure 2. Example of Deck Configuration for the CAASE Programs



```
//                   VOL    =REF=*.FT04F001
//                   DCB=(RECFM=FB,BLKSIZE=2970,LRECL=198,DEN=2),          2
//G.FT04F006 DD DSNAME=PLEA,UNIT=TAPE,LABEL=(6,SL),DISP=(NEW,KEEP),        1
//                 VOLUME=REF=*.FT04F001
//                 DCB=(RECFM=FB,BLKSIZE=2970,LRECL=198,DEN=2),            2
//G.FT04F005 DD DSNAME=JACK,UNIT=TAPE,LABEL=(5,SL),DISP=(NEW,KEEP),        1
//               VOLUME=REF=*.FT04F001
//               DCB=(RECFM=FB,BLKSIZE=2970,LRECL=198,DEN=2),              2
//G.FT04F004 DD DSNAME=USSH,UNIT=TAPE,LABEL=(4,SL),DISP=(NEW,KEEP),        1
//               VOLUME=REF=*.FT04F001
//               DCB=(RECFM=FB,BLKSIZE=2970,LRECL=198,DEN=2),              2
//G.FT04F003 DD DSNAME=NORG,UNIT=TAPE,LABEL=(3,SL),DISP=(NEW,KEEP),        1
//               VOLUME=REF=*.FT04F001
//               DCB=(RECFM=FB,BLKSIZE=2970,LRECL=198,DEN=2),              2
//G.FT04F002 DD DSNAME=MEIG,UNIT=TAPE,LABEL=(2,SL),DISP=(NEW,KEEP),        1
//               VOLUME=SER=RE0087
//               DCB=(RECFM=FB,BLKSIZE=2970,LRECL=198,DEN=2),              2
//G.FT04F001 DD DSNAME=ATHE,UNIT=TAPE,LABEL=(1,SL),DISP=(NEW,KEEP),        1
                  -- OBJECT DECK(S) --
//L.SYSIN DD *
// EXEC FTGLGO
//CAASE1 JOB RTI.C43.PD2804.TUCC,'HAWS, PKBMAR',MSGLEVEL=1,PRTY=0,   .  1
```

Figure 3. JCL and Input Data Cards for CAASE1

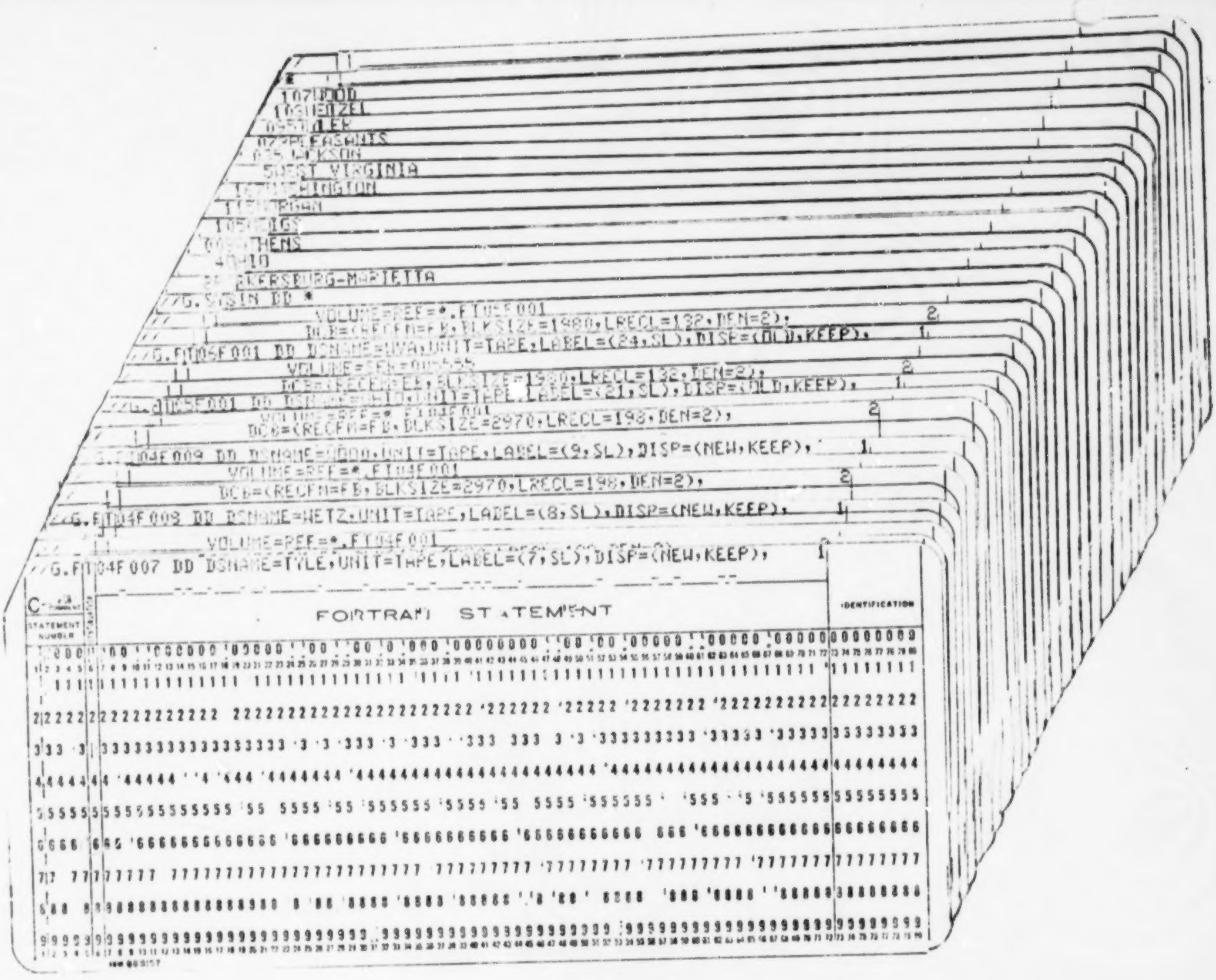

107WOOD
103WENZEL
TYLER
PLEASANTS
JACKSON
WEST VIRGINIA
WASHINGTON
MORGAN
MEIGS
ATHENS
OHIO
PARKERSBURG-MARIETTA
//G.SYSIN DD *
VOLUME=REF=*.FT05F001
DCB=(RECFM=FB,BLKSIZE=1980,LRECL=132,DEN=2),
//G.FT05F001 DD DSNAME=WVA,UNIT=TAPE,LABEL=(24,SL),DISP=(OLD,KEEP),
DCB=(RECFM=FB,BLKSIZE=1980,LRECL=132,DEN=2),
LABEL=(21,SL),DISP=(OLD,KEEP),
VOLUME=REF=*.FT04F001
DCB=(RECFM=FB,BLKSIZE=2970,LRECL=198,DEN=2),
04F009 DD DSNAME=WOOD,UNIT=TAPE,LABEL=(9,SL),DISP=(NEW,KEEP),
VOLUME=REF=*.FT04F001
DCB=(RECFM=FB,BLKSIZE=2970,LRECL=198,DEN=2),
//G.FT04F008 DD DSNAME=WETZ,UNIT=TAPE,LABEL=(8,SL),DISP=(NEW,KEEP),
VOLUME=REF=*.FT04F001
//G.FT04F007 DD DSNAME=TYLE,UNIT=TAPE,LABEL=(7,SL),DISP=(NEW,KEEP),
1
2
FORTRAN STATEMENT
STATEMENT NUMBER
IDENTIFICATION

Figure 3. (Continued)

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TABLE 1. TABLE OF INPUT VARIABLES, CAASE1

VARIABLE NAME	DEFINITION
SCALEX	Scaling factor used to convert the distance in kilometers to plotter inches.
NSTAT	Number of states in AQCR
AQCR	Name of selected Air Quality Control Region
NCNTY	Number of counties in state
STATE	Name of selected state
ICNTY	Federal county code number for selected county
CNTY	Name of selected county

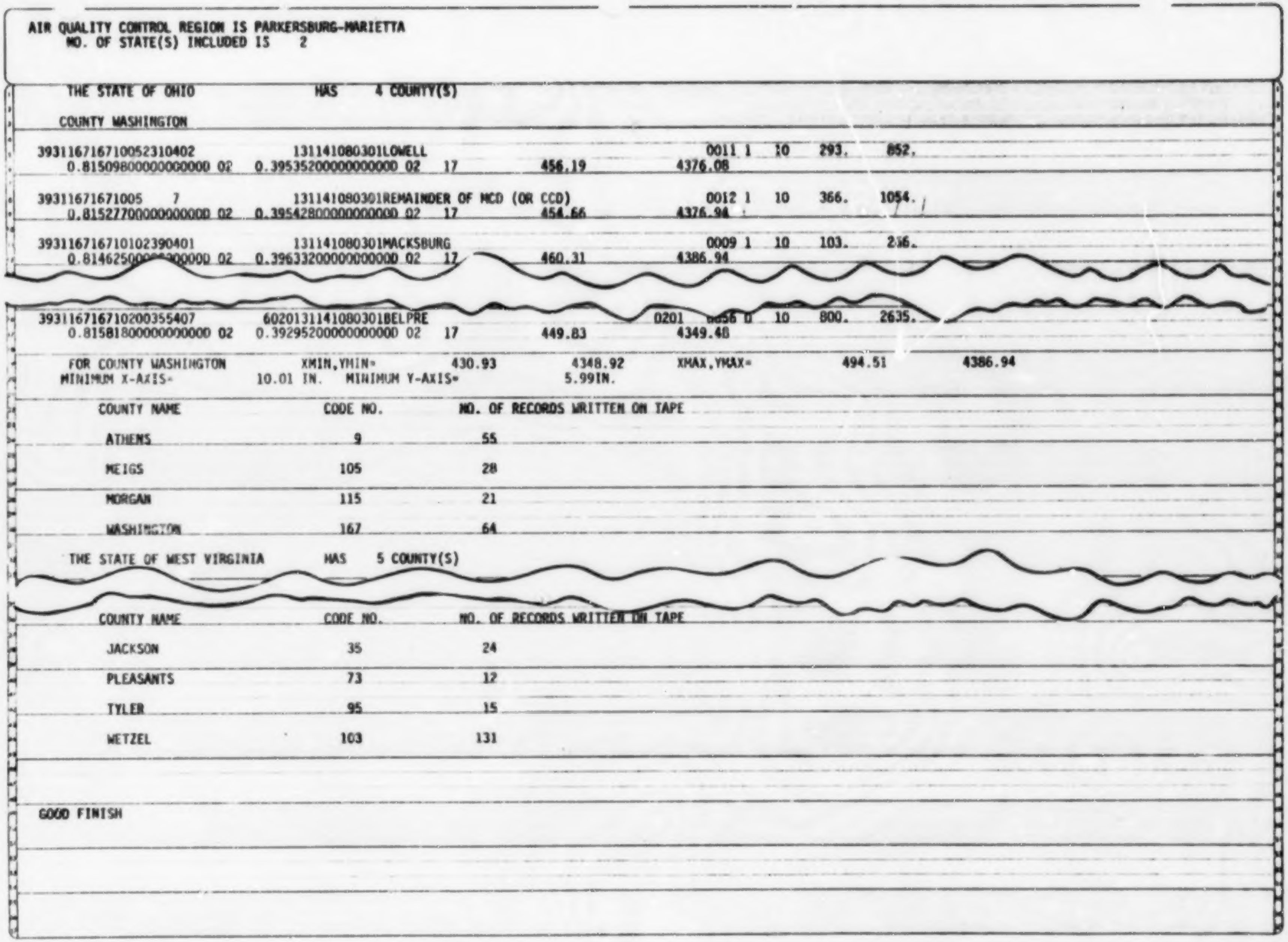
TABLE 2. INPUT CARD LAYOUT, CAASE1

CARD TYPE	COLUMNS	FORMAT	VARIABLE NAME
1	1-12	F12.0	SCALEX
2	1-4	I4	NSTAT
	5-24	5A4	AQCR
3[*]	1-4	I4	NCNTY
	5-24	5A4	STATE
4[†]	1-4	I4	ICNTY
	5-24	5A4	CNTY

---

[*] CARD TYPE 3 is repeated after the set of CARD 4's if the AQCR contains more than one state, and is followed by the necessary CARD 4's.

[†] CARD TYPE 4 is repeated depending on the number of counties in the state.



```
AIR QUALITY CONTROL REGION IS PARKERSBURG-MARIETTA
    NO. OF STATE(S) INCLUDED IS    2

   THE STATE OF OHIO              HAS     4 COUNTY(S)

  COUNTY WASHINGTON

393116716710052310402            131141080301LOWELL                               0011 1   10    293.     852.
     0.815098000000000D 02   0.395352000000000D 02   17           456.19          4376.08

393116716710005    7             131141080301REMAINDER OF MCD (OR CCD)            0012 1   10    366.    1054.
     0.815277000000000D 02   0.395428000000000D 02   17           454.66          4376.94

393116716710102390401            131141080301MACKSBURG                            0009 1   10    103.     256.
     0.814625000000000D 02   0.396332000000000D 02   17           460.31          4386.94

393116716710200355407          602013114108030IBELPRE                      0201   0856 0   10    800.    2635.
     0.815818000000000D 02   0.392952000000000D 02   17           449.83          4349.48

    FOR COUNTY WASHINGTON          XMIN,YMIN=          430.93          4348.92      XMAX,YMAX=          494.51          4386.94
  MINIMUM X-AXIS=            10.01 IN.   MINIMUM Y-AXIS=              5.99IN.

       COUNTY NAME                    CODE NO.           NO. OF RECORDS WRITTEN ON TAPE

        ATHENS                           9                 55

        MEIGS                          105                 28

        MORGAN                         115                 21

        WASHINGTON                     167                 64

    THE STATE OF WEST VIRGINIA       HAS     5 COUNTY(S)

       COUNTY NAME                    CODE NO.           NO. OF RECORDS WRITTEN ON TAPE

        JACKSON                         35                 24

        PLEASANTS                       73                 12

        TYLER                           95                 15

        WETZEL                         103                131


GOOD FINISH
```

Figure 4. Example of a Printout from CAASE1

3.0 CAASE2 PROGRAM

3.1 Program Description

The purpose of this program in the CAASE system is to graphically portray the population centers within the county, both as to location and to number of people in each of the enumeration districts. The program is also used to resolve the problem presented when an Air Quality Control Region straddles a UTM zone boundary. Because the gridding of an AQCR requires a common reference point, when more than one UTM zone lies within the AQCR, one of the zones must be declared the primary zone. The primary zone may be either the westernmost or the easternmost of the two; an input variable is used to indicate which. In most applications thus far, when an AQCR straddled a zone boundary, the western zone has been declared the primary zone and the points falling in the eastern zone have been converted using the subroutine GTGR obtained from EPA. In some cases, to declare the eastern zone the primary zone could yield negative easting coordinates which, at the time of this application, were unacceptable to the Implementation Planning Program (IPP).

Several counties may be processed during a single computer run with this program but the processing is done in series with a separate plotter output picture (map) for each county. A standard picture size of 10.5 inches for the south to north axis and 14.0 inches for the west to east axis usually will be sufficient for plotting a county using a map scale of 1:250,000. Provisions are made in the program to use overriding input variables to produce a picture with a south to north axis up to 29.5 inches. The west to east axis may be of any practical length because the plotter paper is on a continuous roll. When these overriding picture size options are used an "operator message" is issued to enable the operator to change paper on the plotter. Prudence would suggest not mixing standard size plots with "special case" (wide paper) plots. In addition to the subroutine GTGR, which converts coordinates from one UTM zone to another, CAASE2 uses the subroutine POPMAP which places a small triangle in the center of each enumeration district and draws a circle, with radius proportional to the population, around the triangle. The subroutine POPMAP is described in Section 7.3. The CAASE2 program uses two types of input data, (1) the edited MED-X data tape output from CAASE1, and (2) punched cards to specify the values of variables including scaling factors, optional picture size, and labeling information for the county (or counties) being processed. Outputs include a plotted map depicting the location and population of each enumeration district in a county. This map is drawn to the scale of the map which will be used when selecting the grid for the AQCR being processed. Also output from this program are diagnostic messages, error messages when necessary, and a summary of records plotted for each county processed. A logical flow chart describing CAASE2 is included in Appendix B. Subroutine GTGR is described in Section 7.2.

3.2 Job Control Language (JCL) and Deck Setup

An example of the deck setup configuration is illustrated in Figure 2. The JCL cards associated with an example to plot Washington County, Ohio, in the Parkersburg-Marietta AQCR, are illustrated in Figure 5. The JCL configuration illustrated assumes the following:

a. The program is in object deck form.

b. The punched cards assigning values to the variables are in the job input stream.

c. The population data are on magnetic tape, and were output from CAASE1 on reel number RED087 as file number four.

d. The number of counties to be processed is one and can be plotted using the standard 10.5 inches by 14.0 inches plotting picture.

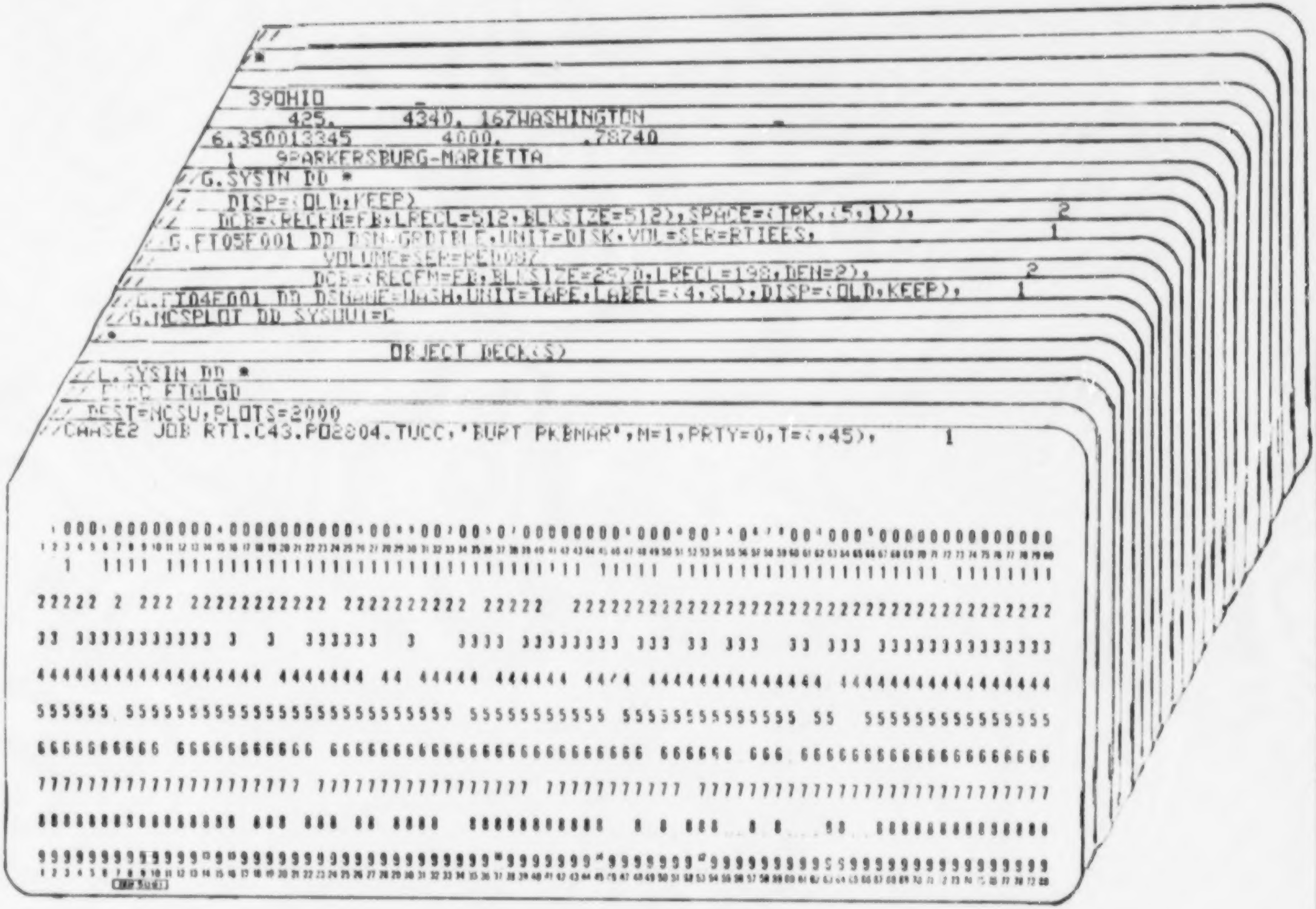
e. The tables used by the GTGR subroutine are on a disk (not needed for this AQCR, but JCL cards are included in the example).

3.3 Input Information

The punched card input variables appear in Table 3. They include the number of counties to be plotted for the AQCR during this computer run, the total number of counties in the AQCR, the AQCR name, the primary UTM zone, the east-west direction to convert coordinates to the primary zone when the AQCR straddles a UTM zone boundary, the scaling factors to convert population to the radius of a circle (in plotter space inches), and the spacing between axes tick-marks. Also input for each county to be plotted are cards containing the UTM coordinates for an appropriate origin, the county code, county name, state code and state name, and an axes flag to indicate whether the standard axes lengths will be used. For a county requiring longer axes than standard, input cards are necessary specifying the length (in inches of plotter space) of the X and Y axes and the number of tick-marks required. The input card layout is described in Table 4.

3.4 Output Information

Output from CAASE2 includes the printing of the AQCR name, total number of counties in the AQCR, and the number of counties plotted. Also output on the printer are the distance and population scaling factors, and any error messages returned from subroutines POPMAP and GTGR. At the end of the processing of all counties for any computer run, the county names, their numbers, and the number of records plotted for each county are also printed. See Figure 6 for an example of the printed output for Washington County, Ohio and Figure 7 for the plotter output.



```
//
/*

 39OHIO
     425.      4340. 167WASHINGTON
6.350013345        4000.       .78740
 1    9PARKERSBURG-MARIETTA
//G.SYSIN DD *
//   DISP=(OLD,KEEP)
//   DCB=(RECFM=FB,LRECL=512,BLKSIZE=512),SPACE=(TRK,(5,1)),              2
//G.FT05F001 DD DSN=GRDTBLE,UNIT=DISK,VOL=SER=RTIEES,                    1
//              VOLUME=SER=RE0087
//              DCB=(RECFM=FB,BLKSIZE=2970,LRECL=198,DEN=2),            2
//G.FT04F001 DD DSNAME=WASH,UNIT=TAPE,LABEL=(4,SL),DISP=(OLD,KEEP),     1
//G.NCSPLOT DD SYSOUT=C
/*
                       OBJECT DECK(S)
//L.SYSIN DD *
// EXEC FTGLGD
// DEST=NCSU,PLOTS=2000
//CAASE2 JOB RTI.C43.PD2804.TUCC,'BURT PKBNAR',M=1,PRTY=0,T=(,45),      1
```

Figure 5. JCL and Input Data Cards for CAASE2

TABLE 3. TABLE OF INPUT VARIABLES, CAASE2

VARIABLE NAME	DEFINITION
NCNTY	Number of counties to be plotted
ITOT	Number of counties in the AQCR
AQCR	Name of Air Quality Control Region
IZONE	Primary UTM zone
EW	Direction of coordinate point conversion for primary zone when AQCR straddles UTM zones
SCALEX	Scaling factor to convert distances in kilometers to plotter inches
SCALEP	Scaling factor to convert population to circle radius in inches
TICINC	Distance between axes tick-marks in inches
XXZERO	Lower left-hand X coordinate of the selected county
YYZERO	Lower left-hand Y coordinate of the selected county
ICNTY	Federal county code for selected county
XCNTY	Name of selected county
IAXES	Axes flag signifying whether the standard axes will be used
ISTAT	Federal state code number for selected state
XSTAT	Name of selected state
XLONG	Length of X axis if standard X axis is too short
YLONG	Length of Y axis if standard Y axis is too short
XTIC	Number of tick-marks on lengthened X axis
YTIC	Number of tick-marks on lengthened Y axis

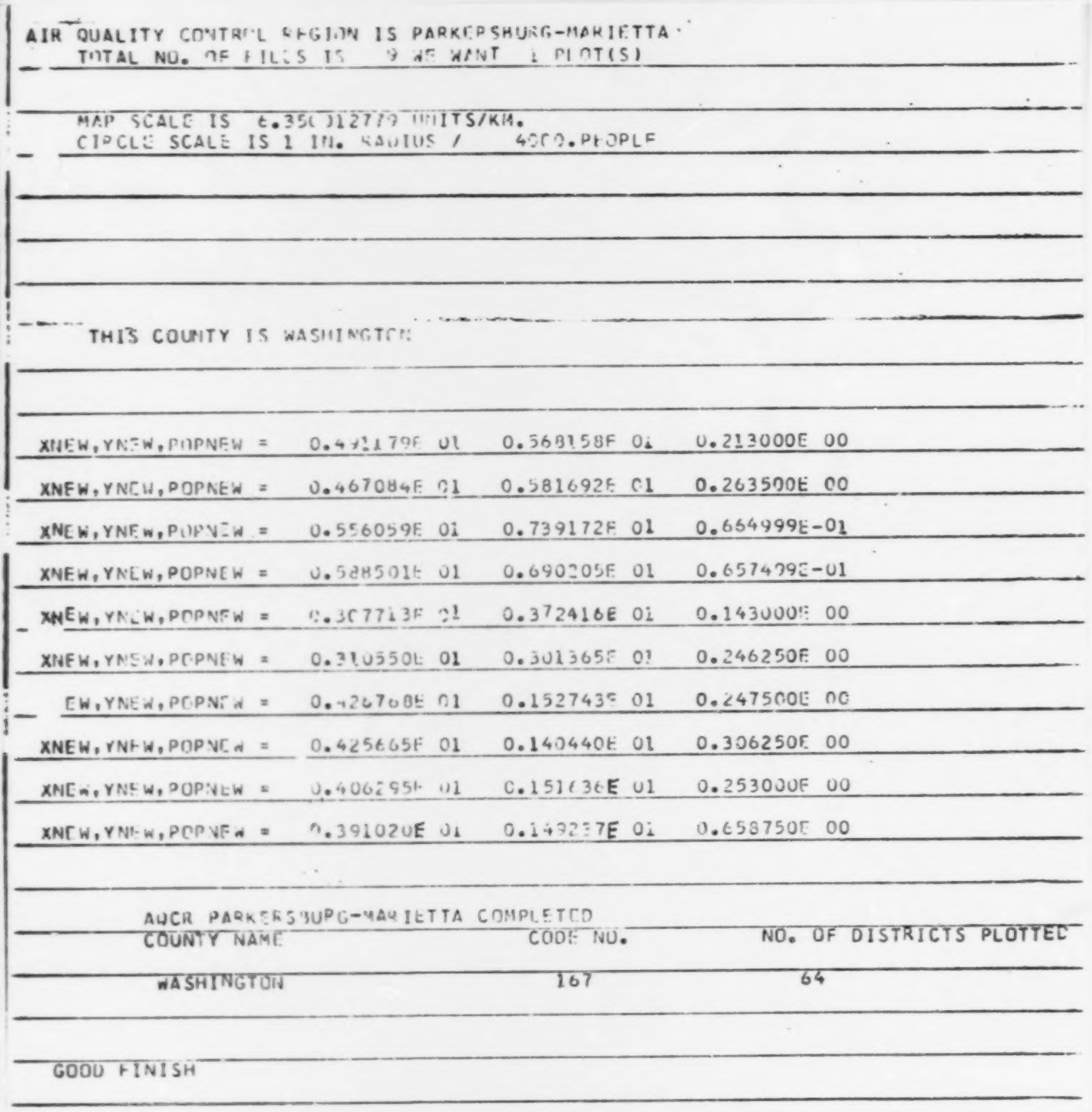
TABLE 4. INPUT CARD LAYOUT, CAASE2

CARD TYPE	COLUMNS	FORMAT	VARIABLE NAME
1	1-4	I4	NCNTY
	5-8	I4	ITOT
	9-28	5A4	AQCR
	31-35	I5	IZONE
	36-40	F5.0	EW
2	1-12	F12.0	SCALEX
	13-24	F12.0	SCALEP
	25-36	F12.0	TICINC
3*	1-10	F10.0	XXZERO
	11-20	F10.0	YYZERO
	21-24	I4	ICNTY
	25-48	6A4	XCNTY
	51-52	I2	IAXES
4*	1-4	I4	ISTAT
	5-16	3A4	XSTAT
5†	1-10	F10.0	XLONG
	11-20	F10.0	YLONG
	21-25	I5	XTIC
	26-30	I5	YTIC

---

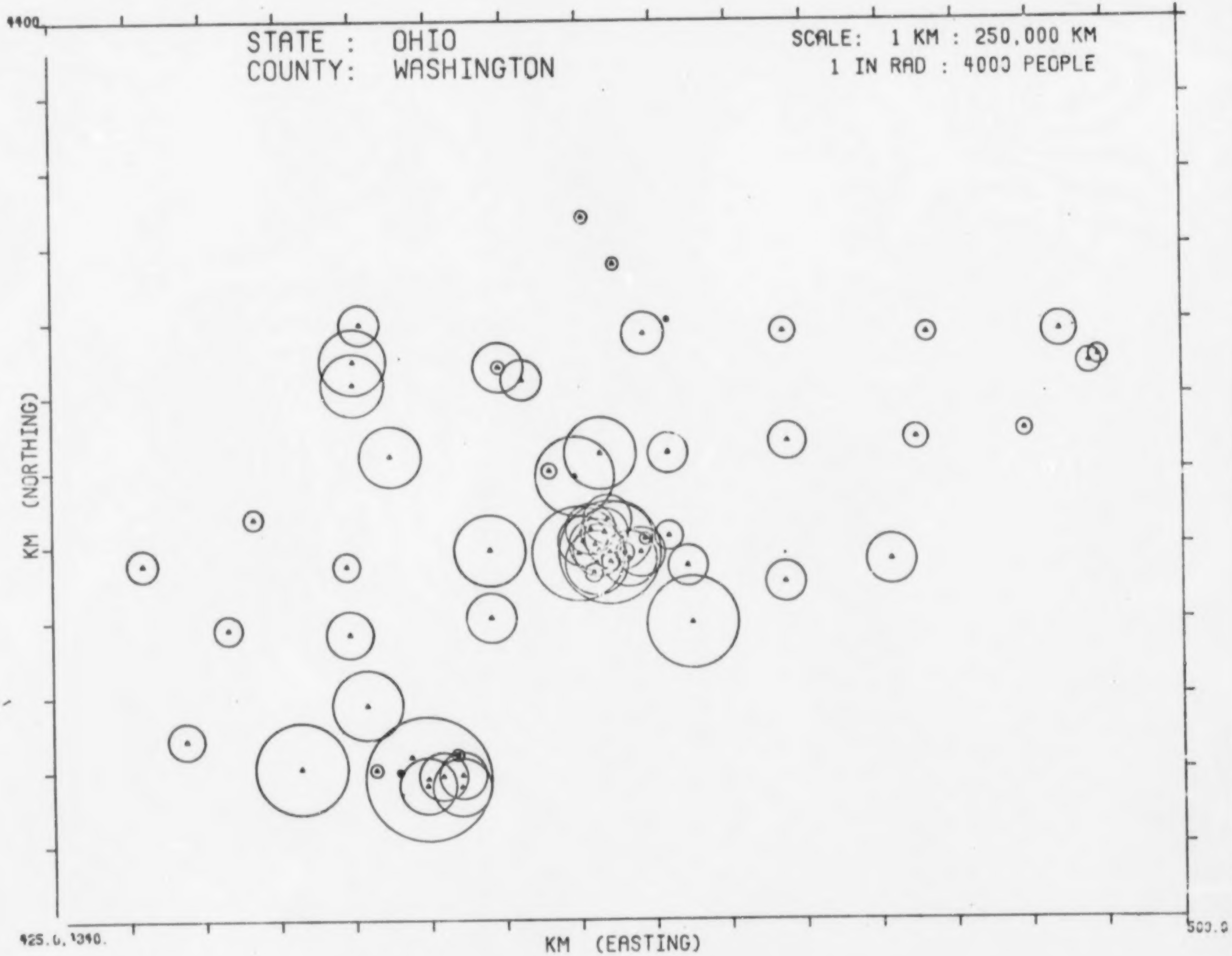
*CARD TYPES 3 and 4 are repeated depending on number of counties to be plotted.

†CARD TYPE 5 is used ONLY if the county requires longer axes.



```
AIR QUALITY CONTROL REGION IS PARKERSBURG-MARIETTA
   TOTAL NO. OF FILES IS    9 WE WANT  1 PLOT(S)

   MAP SCALE IS  6.350012779 UNITS/KM.
   CIRCLE SCALE IS 1 IN. RADIUS /    4000.PEOPLE




    THIS COUNTY IS WASHINGTON



 XNEW,YNEW,POPNEW =    0.491179E 01    0.568158E 01    0.213000E 00
 XNEW,YNEW,POPNEW =    0.467084E 01    0.581692E 01    0.263500E 00
 XNEW,YNEW,POPNEW =    0.556059E 01    0.739172E 01    0.664999E-01
 XNEW,YNEW,POPNEW =    0.588501E 01    0.690205E 01    0.657499E-01
 XNEW,YNEW,POPNEW =    0.307713E 01    0.372416E 01    0.143000E 00
 XNEW,YNEW,POPNEW =    0.310550E 01    0.301365E 01    0.246250E 00
   EW,YNEW,POPNEW =    0.426768E 01    0.152743E 01    0.247500E 00
 XNEW,YNEW,POPNEW =    0.425665E 01    0.140440E 01    0.306250E 00
 XNEW,YNEW,POPNEW =    0.406295E 01    0.151636E 01    0.253000E 00
 XNEW,YNEW,POPNEW =    0.391020E 01    0.149237E 01    0.658750E 00


       AQCR PARKERSBURG-MARIETTA COMPLETED
       COUNTY NAME                    CODE NO.          NO. OF DISTRICTS PLOTTED

        WASHINGTON                     167               64


  GOOD FINISH
```

Figure 6. Example of a Printout from CAASE2


STATE : OHIO
COUNTY: WASHINGTON
SCALE: 1 KM : 250,000 KM
1 IN RAD : 4000 PEOPLE
4400
425.0, 4340.
500.0
KM (NORTHING)
KM (EASTING)

mple of a Plotter C

4.0 CAASE3 PROGRAM

4.1 Program Description

The CAASE3 program is designed to draw area source grid squares for any given AQCR. It uses a set of data cards that define, for each grid square within the AQCR, the coordinates of the lower left-hand corner and the side length. The program is useful for identifying clerical errors or keypunching errors and for describing the locations and sizes of each of the grid squares within an AQCR. A scaling factor appropriate for the map with which the grid will be used may be input; the only restriction is the physical limitations of the plotter paper width. CAASE3 calls the subroutine POPBOX and provides to it the necessary information to drive the plotter to draw the AQCR grid. Subroutine POPBOX is described in Section 7.4. Because most AQCR's contain several counties, the 30-inch-wide paper probably will be necessary for CAASE3 plotting and an "operator message" requesting the wide paper is issued by the program in all cases. A flow chart of the program logic of CAASE3 appears in Appendix C.

4.2 Job Control Language (JCL) and Deck Setup

An example of a deck setup configuration is illustrated in Figure 2. The JCL cards associated with an example for the Parkersburg-Marietta AQCR are illustrated in Figure 8. The JCL configuration illustrated assumes the following:

a. The program is in object deck form.

b. The punched cards assigning values to the variables are in the job input stream.

c. The punched cards describing the grid squares and their locations are in the job input stream.

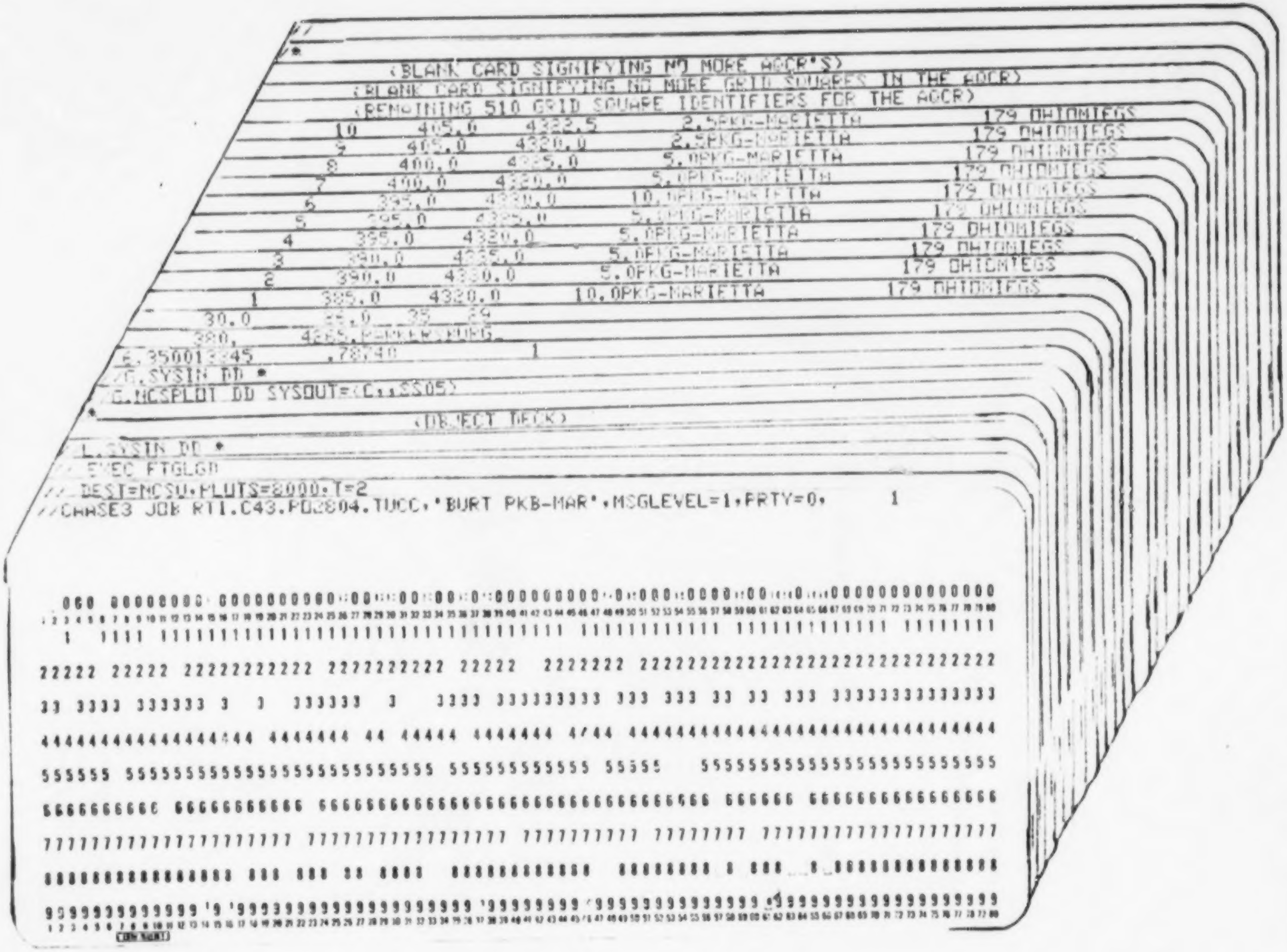
d. Only one Air Quality Control Region (AQCR) is to be plotted.

4.3 Input Information

All input to the CAASE3 program is through punched cards in the input stream. The punched card input variables appear in Table 5. Input variables define the scaling factor, the UTM coordinates of the lower left-hand corner of the entire AQCR, the AQCR name, the length in plotter space inches of both the X and Y axes, the number of tick-marks wanted on both the X and Y axes, the spacing of the tick-marks, and a card for each grid square in the AQCR which contains the identification number of the grid square, the UTM coordinates of the lower left-hand corner, and the side length of the grid square. The input card layout is described in Table 6.

4.4 Output Information

In addition to a computer driven plotter output of all grid squares (see Figure 9 for an example) within the AQCR drawn to scale, error messages, when necessary, and a listing of input data are printed. Figure 10 is an example of the printed output.



```
//CAASE3 JOB RT1.C43.PD2804.TUCC,'BURT PKB-MAR',MSGLEVEL=1,PRTY=0,      1
//  DEST=MCSU,PLUTS=8000,T=2
//  EXEC FTGLGO
//L.SYSIN DD *
                         (OBJECT DECK)
/*
//G.MCSPLOT DD SYSOUT=(C,,SS05)
//G.SYSIN DD *
6.350013345       .78740             1
   380,       4265,PARKERSBURG
    30.0         35.0   35   29
          1     385.0    4320.0        10.0PKG-MARIETTA             179 OHIOMIEGS
           2     390.0    4330.0        5.0PKG-MARIETTA             179 OHIOMIEGS
            3     390.0    4325.0        5.0PKG-MARIETTA             179 OHIOMIEGS
             4     395.0    4320.0        5.0PKG-MARIETTA             179 OHIOMIEGS
              5     395.0    4325.0        5.0PKG-MARIETTA             179 OHIOMIEGS
               6     395.0    4330.0        10.0PKG-MARIETTA            179 OHIOMIEGS
                7     400.0    4320.0        5.0PKG-MARIETTA             179 OHIOMIEGS
                 8     400.0    4325.0        5.0PKG-MARIETTA             179 OHIOMIEGS
                  9     405.0    4320.0        2.5PKG-MARIETTA             179 OHIOMIEGS
                  10    405.0    4322.5        2.5PKG-MARIETTA             179 OHIOMIEGS
                  (REMAINING 510 GRID SQUARE IDENTIFIERS FOR THE AQCR)
                  (BLANK CARD SIGNIFYING NO MORE GRID SQUARES IN THE AQCR)
                   (BLANK CARD SIGNIFYING NO MORE AQCR'S)
/*
//
```

Figure 8. JCL and Input Data Cards for CAASE3

TABLE 5. TABLE OF INPUT VARIABLES, CAASE3

VARIABLE NAME	DEFINITION
SCALEX	Scaling factor to convert distances in kilometers to plotter inches
TICINC	Distance between axes tick-marks in inches
XZERO	Lower left-hand X coordinate for entire AQCR
YZERO	Lower left-hand Y coordinate for entire AQCR
AQCR	Name of selected Air Quality Control Region
XLONG	Length of X axis
YLONG	Length of Y axis
IXTIC	Number of tick-marks on X axis
IYTIC	Number of tick-marks on Y axis
IBOX	Area source grid square number
XPT	Lower left-hand X coordinate for the grid square
YPT	Lower left-hand Y coordinate for the grid square
S	Length of the side of the grid square
CNTY	Name of county to which grid square belongs

TABLE 6. INPUT CARD LAYOUT, CAASE3

CARD TYPE	COLUMNS	FORMAT	VARIABLE NAME
1	1-12	F12.0	SCALEX
	13-24	F12.0	TICINC
2	1-10	F10.0	XZERO
	11-20	F10.0	YZERO
	21-40	5A4	AQCR
3	1-10	F10.0	XLONG
	11-20	F10.0	YLONG
	21-25	I5	IXTIC
	26-30	I5	IYTIC
4*	1-10	I10	IBOX
	11-20	F10.0	XPT
	21-30	F10.0	YPT
	31-40	F10.0	S
	71-78	2A4	CNTY
5	A blank card indicating no more grid squares for this AQCR.		
6	A blank card indicating no more AQCR's to be gridded.		

---

*CARD TYPE 4 is repeated for each grid square in the AQCR.

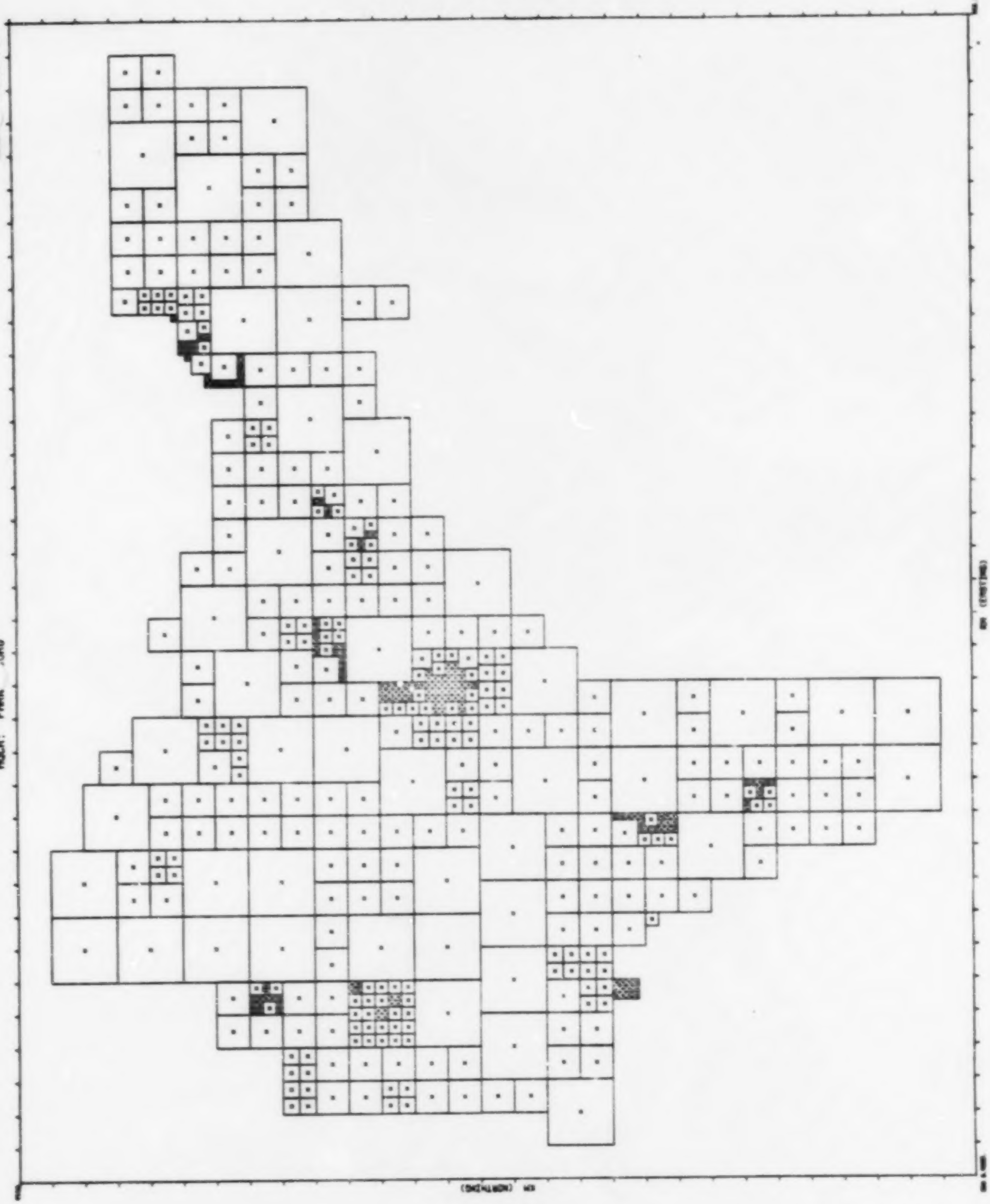
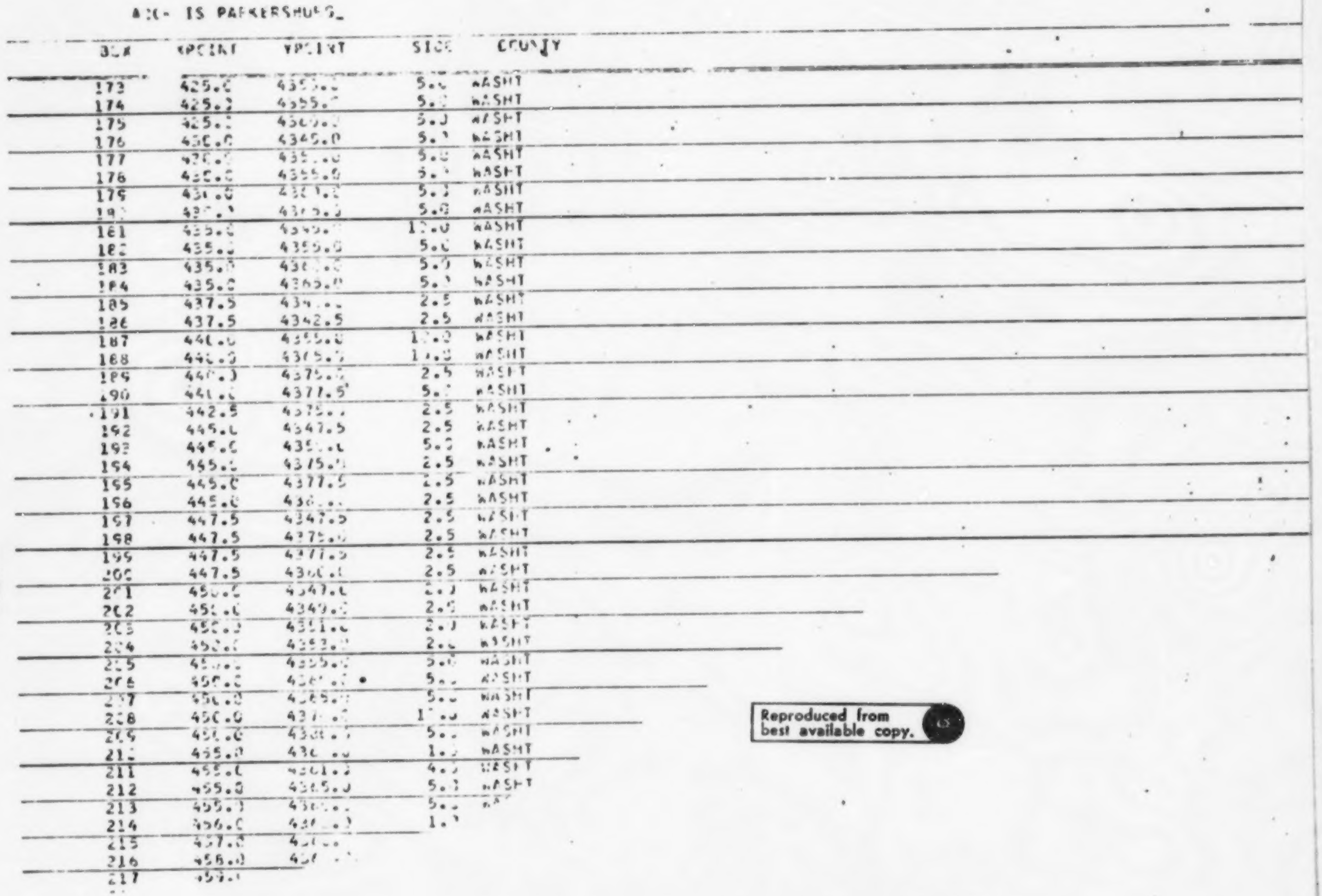

SCALE 1:250,000 KM
ROCR: PARA. URG
KM (EASTING)
KM (NORTHING)

Figure 9. Example of a Plotter Output from CAASE3
(Figure Optically Reduced)



```
      ARC- IS PARKERSBURG

      BOX   XPOINT   YPOINT    SIZE   COUNTY

      173   425.0    4350.0     5.0   WASHT
      174   425.0    4355.0     5.0   WASHT
      175   425.0    4360.0     5.0   WASHT
      176   430.0    4345.0     5.0   WASHT
      177   430.0    4350.0     5.0   WASHT
      178   430.0    4355.0     5.0   WASHT
      179   430.0    4360.0     5.0   WASHT
      180   430.0    4365.0     5.0   WASHT
      181   435.0    4345.0    10.0   WASHT
      182   435.0    4355.0     5.0   WASHT
      183   435.0    4360.0     5.0   WASHT
      184   435.0    4365.0     5.0   WASHT
      185   437.5    4340.0     2.5   WASHT
      186   437.5    4342.5     2.5   WASHT
      187   440.0    4355.0    10.0   WASHT
      188   440.0    4365.0    10.0   WASHT
      189   440.0    4375.0     2.5   WASHT
      190   440.0    4377.5     5.0   WASHT
      191   442.5    4375.0     2.5   WASHT
      192   445.0    4347.5     2.5   WASHT
      193   445.0    4350.0     5.0   WASHT
      194   445.0    4375.0     2.5   WASHT
      195   445.0    4377.5     2.5   WASHT
      196   445.0    4360.0     2.5   WASHT
      197   447.5    4347.5     2.5   WASHT
      198   447.5    4375.0     2.5   WASHT
      199   447.5    4377.5     2.5   WASHT
      200   447.5    4360.0     2.5   WASHT
      201   450.0    4347.0     2.0   WASHT
      202   450.0    4349.0     2.0   WASHT
      203   450.0    4351.0     2.0   WASHT
      204   450.0    4353.0     2.0   WASHT
      205   450.0    4355.0     5.0   WASHT
      206   450.0    4360.0     5.0   WASHT
      207   450.0    4365.0     5.0   WASHT
      208   450.0    4370.0    10.0   WASHT
      209   450.0    4380.0     5.0   WASHT
      210   455.0    4360.0     1.0   WASHT
      211   455.0    4361.0     4.0   WASHT
      212   455.0    4365.0     5.0   WASHT
      213   455.0    [illegible] 5.0  WA[illegible]
      214   456.0    [illegible] 1.0
      215   457.0    [illegible]
      216   458.0    [illegible]
      217   459.0
```

Reproduced from best available copy.

Figure 10. Example of a Printer Output from CAASE3

5.0 CAASE4 PROGRAM

5.1 Description of Program

The CAASE4 apportioning factor program uses the edited MED-X data files, with UTM coordinates (output from CAASE1) and cards describing the lower left-hand corner and side length of each area source grid square and processes the census data to sum all of the population and housing counts for all enumeration districts with centers falling within each individual grid square. The area of each grid square is also calculated. Because the MED-X data locates the geographical center of the enumeration district, the basic question is whether the center falls within the geographic outline of the grid square. These population summations, housing summations, and areas for each grid square are objective factors used in the apportioning of total county emissions, for each of the source emissions categories, into grid squares of unequal size which have been subjectively located using graphical outputs from CAASE2. Because there are source categories, e.g. airports, which do not lend themselves to objective apportioning based on population, housing, or area, provisions are made in the CAASE4 program to input, as overriding weighting factors, any information known to the technical personnel gridding the county (or counties) within the AQCR and apportioning the county total emissions. These weighting factors override the objective apportioning factors. A detailed discussion of the objective apportioning factors and the overriding apportioning weighting factors, their rationale, and how to apply them, are included in Section 9.0 of this manual.

For convenience, the several fields of "fuel" data on the Area Source Input Form EPA (DUR) 219 3/72 have been sequentially numbered for category number, major classification (residential fuel, industrial fuel, etc.), and minor classification (anthracite coal, bituminous coal, distillate oil, etc.). Table 7 relates the category number to its major and minor classifications, and the method of introducing overriding apportioning factors is discussed in Section 5.3, Input Data.

The CAASE4 program also relates all locations to a common origin, i.e., in using the CAASE1 output tape of census data, more than one UTM zone may be encountered;

TABLE 7. AREA SOURCE EMISSIONS CATEGORY NUMBERS

CATEGORY NUMBER	MAJOR CLASSIFICATION	MINOR CLASSIFICATION
1	RESIDENTIAL FUEL	ANTHRACITE COAL
2	RESIDENTIAL FUEL	BITUMINOUS COAL
3	RESIDENTIAL FUEL	DISTILLATE OIL
4	RESIDENTIAL FUEL	RESIDUAL OIL
5	RESIDENTIAL FUEL	NATURAL GAS
6	RESIDENTIAL FUEL	WOOD
7	COMMERCIAL & INSTITUTIONAL FUEL	ANTHRACITE COAL
8	COMMERCIAL & INSTITUTIONAL FUEL	BITUMINOUS COAL
9	COMMERCIAL & INSTITUTIONAL FUEL	DISTILLATE OIL
10	COMMERCIAL & INSTITUTIONAL FUEL	RESIDUAL OIL
11	COMMERCIAL & INSTITUTIONAL FUEL	NATURAL GAS
12	COMMERCIAL & INSTITUTIONAL FUEL	WOOD
13	INDUSTRIAL FUEL	ANTHRACITE COAL
14	INDUSTRIAL FUEL	BITUMINOUS COAL
15	INDUSTRIAL FUEL	COKE
16	INDUSTRIAL FUEL	DISTILLATE OIL
17	INDUSTRIAL FUEL	RESIDUAL OIL
18	INDUSTRIAL FUEL	NATURAL GAS
19	INDUSTRIAL FUEL	WOOD
20	INDUSTRIAL FUEL	PROCESS GAS
21	ON-SITE INCINERATION	RESIDENTIAL
22	ON-SITE INCINERATION	INDUSTRIAL
23	ON-SITE INCINERATION	COMMERCIAL & INSTITUTIONAL FUEL
24	OPEN BURNING	RESIDENTIAL
25	OPEN BURNING	INDUSTRIAL
26	OPEN BURNING	COMMERCIAL & INSTITUTIONAL FUEL
27	GASOLINE FUEL	LIGHT VEHICLE
28	GASOLINE FUEL	HEAVY VEHICLE
29	GASOLINE FUEL	OFF-HIGHWAY
30	DIESEL FUEL	HEAVY VEHICLE
31	DIESEL FUEL	OFF-HIGHWAY
32	DIESEL FUEL	RAIL LOCOMOTIVE
33	AIRCRAFT	MILITARY
34	AIRCRAFT	CIVIL
35	AIRCRAFT	COMMERCIAL
36	VESSELS	ANTHRACITE COAL
37	VESSELS	DIESEL OIL
38	VESSELS	RESIDUAL OIL
39	VESSELS	GASOLINE
40	EVAPORATION	SOLVENT PURCHASED
41	EVAPORATION	GASOLINE MARKETED
42	MEASURED VEHICLE MILES	LIMITED ACCESS ROADS
43	MEASURED VEHICLE MILES	RURAL ROADS
44	MEASURED VEHICLE MILES	SUBURBAN ROADS
45	MEASURED VEHICLE MILES	URBAN ROADS
46	DIRT ROADS TRAVELED	...
47	DIRT AIRSTRIPS	...
48	CONSTRUCTION LAND AREA	...
49	ROCK HANDLING & STORING	...
50	FOREST FIRES*	AREA-ACRES
51	SLASH BURNING*	AREA-ACRES
52	FROST CONTROL**	ORCHARD HEATERS
53	STRUCTURE FIRES	NUMBER PER YEAR
54	COAL REFUSE BURNING***	SIZE OF BANK

---

*Tons/acre also reported; **Days/yr. fired also reported; ***Number/yr. also reported.

therefore, a primary zone is declared on an input card and those points falling outside the primary zone have their UTM coordinates converted to the primary zone. The conversion is made using subroutine GTGR which is described in Section 7.2. In the CAASE4 program objective apportioning factors have been assigned for all area source emission categories, even though emission factors have not yet been determined for some. CAASE4 will not require modification (except to change the coefficient from zero) when these emission factors are determined. The tons per acre coefficients reported on the Area Source Form No. EPA (DUR) 219 3/72 for forest fires and slash burning is used to calculate total county "fuels" for those source categories and are therefore not subject to apportioning; their numeric value is included in CAASE4 outputs for use by CAASE5. The number of days orchard heaters are fired for frost control and the number of burns/year of coal refuse banks are also output without change for use by CAASE5. A logical flow chart describing CAASE4 is included in Appendix D.

5.2 Job Control Language (JCL) and Deck Setup

An example of a deck setup configuration is illustrated in Figure 2. The JCL cards associated with an example for the Parkersburg-Marietta AQCR are illustrated in Figure 11. The JCL configuration illustrated assumes the following:

a. The program is in object deck form.

b. The punched cards assigning values to the variables are in the job input stream.

c. Population data, output from CAASE1, are on magnetic tape as files 1 through 9 on reel number RED087.

d. The number of counties to be processed is nine.

e. The tables used by the GTGR subroutine are on disk volume "RTIEES" with data set name (DSN) of "GRDTB66."

f. No overriding apportioning weighting factors are input.

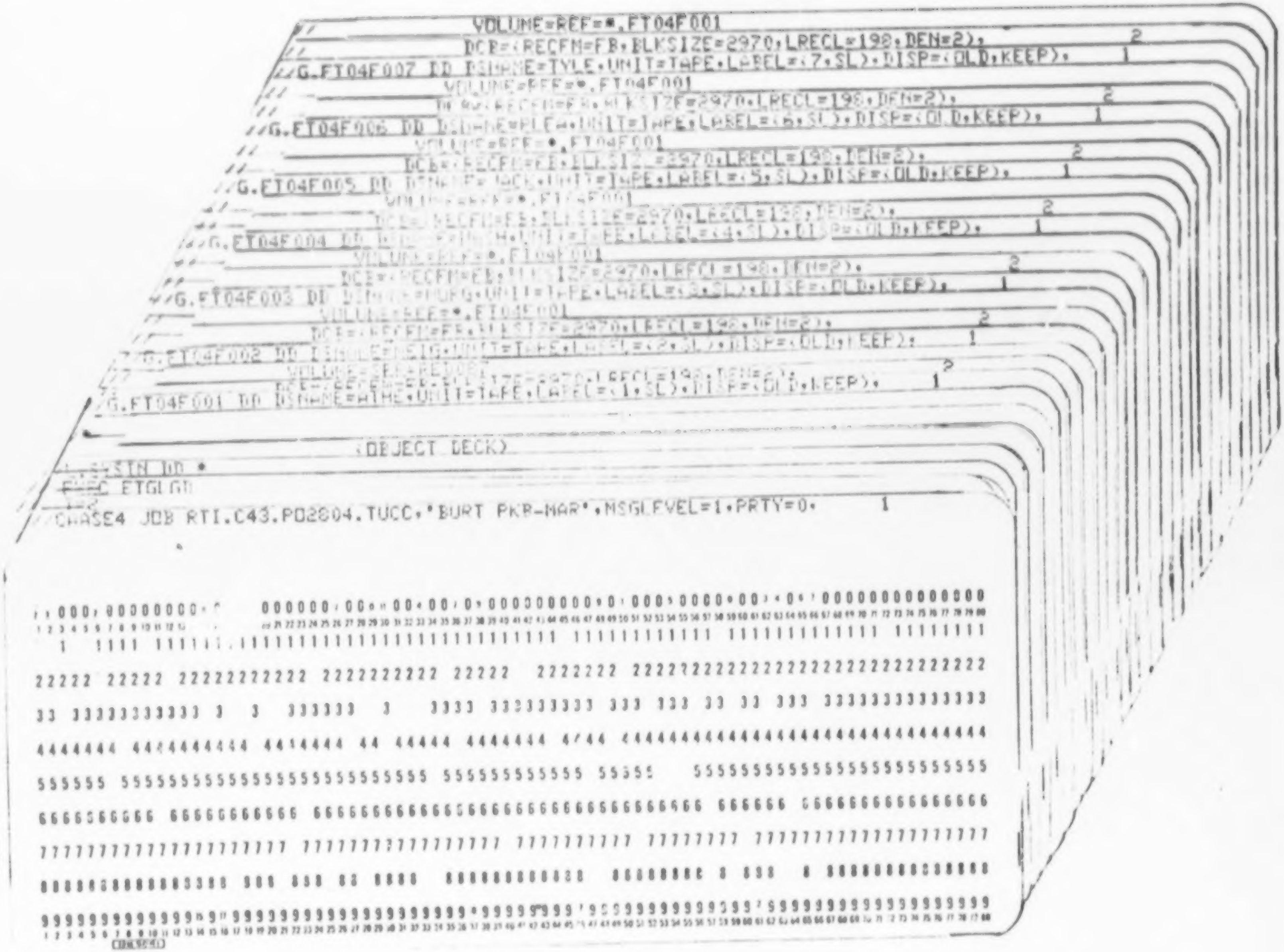
g. Output of apportioning factors is on binary tape as files 1 through 9 on reel number RED141 (for later use by CAASE5).

5.3 Input Information

The punched card input variables appear in Table 8. They include the county, region, political subdivision, county name, primary UTM zone number, a print switch option variable, and a direction variable to convert coordinates when an AQCR straddles UTM zone boundaries. The same grid square identification cards which were used as input to the CAASE3 program are used as input to CAASE4; that is, a card is input for each grid square containing its sequential identification number, UTM coordinates of the lower left-hand corner, and its side length in kilometers. Overriding weighting factor cards are read in until a blank card is encountered. Each weighting factor card includes the identification number of a grid square, a source category number, and the weighting value to be assigned. A card is necessary for each grid square and source category combination for which an overriding weighting factor is to be input. The edited MED-X tape, output from CAASE1, is read by the program a record at a time, and the housing counts and population counts are summed into the grid square into which each enumeration district center falls. If a decision is made at processing time to assign equal weighting factors to some normally overridden source category, such as railroads, then it is suggested that the FORTRAN source language statement be inserted near the end of the weighting factor initialization loop to set the coefficient (weighting factor) to 1.0 instead of 0. This will preclude the necessity of inputting a large volume of cards. The description of the input card layout appears in Table 9.

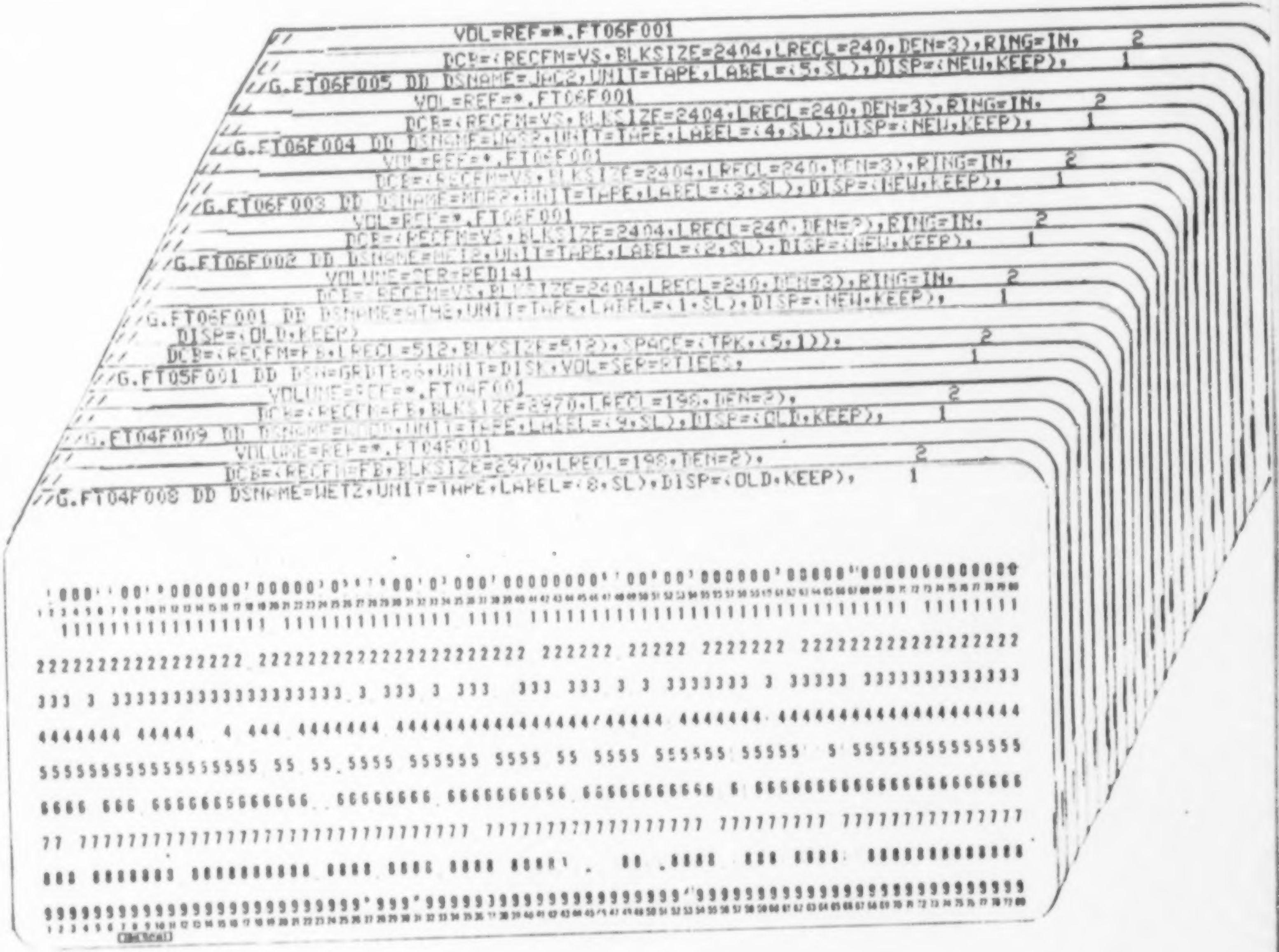
5.4 Output Information

Error messages, diagnostic messages, information necessary to control the CAASE5 program, and a magnetic tape with grid square descriptors and their weighted apportioning factors are output. The county, region, political subdivision, and county name from the input information are printed. For each county, the grid square number, category number, and weighting factor number for each overriding weighting factor read in are printed; the total count of overriding weighting factors is also printed. The total number of grid squares for each county is printed. Error and diagnostic messages (and suggested responses) include: the number of grid squares for a county exceeds the program dimensions (increase the dimensions and rerun); a category number on an overriding weighting factor input card is out of range (correct it); the grid square number on an overriding weighting factor card does not match any of the set for the county being processed (correct the set or the card); a message when the county number on the tape input file and the one on the input card do not match (JCL or input card error, correct it); any error messages from grid-to-grid coordinate conversion routine GTGR (see Section 7.2.3); and an optional print of census data and UTM coordinates. If an enumeration district's coordinates are not located inside any grid square uniquely assigned to the county being processed, its county number, UTM coordinates, population, and housing counts are printed. The coordinates should be checked on the total AQCR grid against the following possibilities: 1) the coordinates are not located within the county and are therefore incorrect on the census record, 2) the grid square in which the coordinates are located was either assigned to the wrong county, was not included in the deck, or was keypunched wrong, 3) it was not possible to draw a grid square at the county border without including an enumeration district from an adjacent county and a compromise was made. The apportioning factor computed for each grid square can also be optionally printed. Figure 12 is an example of the printout from the processing of the Parkersburg-Marietta AQCR.



```
//                VOLUME=REF=*.FT04F001
//                 DCB=(RECFM=FB,BLKSIZE=2970,LRECL=198,DEN=2),      2
//G.FT04F007 DD DSNAME=TYLE,UNIT=TAPE,LABEL=(7,SL),DISP=(OLD,KEEP),   1
//              VOLUME=REF=*.FT04F001
//               DCB=(RECFM=FB,BLKSIZE=2970,LRECL=198,DEN=2),        2
//G.FT04F006 DD DSNAME=[illegible],UNIT=TAPE,LABEL=(6,SL),DISP=(OLD,KEEP),   1
//             VOLUME=REF=*.FT04F001
//              DCB=(RECFM=FB,BLKSIZE=2970,LRECL=198,DEN=2),         2
//G.FT04F005 DD DSNAME=JACK,UNIT=TAPE,LABEL=(5,SL),DISP=(OLD,KEEP),   1
//            VOLUME=REF=*.FT04F001
//             DCB=(RECFM=FB,BLKSIZE=2970,LRECL=198,DEN=2),          2
//G.FT04F004 DD DSNAME=[illegible],UNIT=TAPE,LABEL=(4,SL),DISP=(OLD,KEEP),   1
//           VOLUME=REF=*.FT04F001
//            DCB=(RECFM=FB,BLKSIZE=2970,LRECL=198,DEN=2),           2
//G.FT04F003 DD DSNAME=MURG,UNIT=TAPE,LABEL=(3,SL),DISP=(OLD,KEEP),   1
//          VOLUME=REF=*.FT04F001
//           DCB=(RECFM=FB,BLKSIZE=2970,LRECL=198,DEN=2),            2
//G.FT04F002 DD DSNAME=NEIG,UNIT=TAPE,LABEL=(2,SL),DISP=(OLD,KEEP),   1
//         VOLUME=SER=REDOR[illegible]
//          DCB=(RECFM=FB,BLKSIZE=2970,LRECL=198,DEN=2),             2
//G.FT04F001 DD DSNAME=AIME,UNIT=TAPE,LABEL=(1,SL),DISP=(OLD,KEEP),   1
                  (OBJECT DECK)
//SYSIN DD *
// EXEC ETGLGD
//CAASE4 JOB RTI.C43.PD2804.TUCC,'BURT PKR-MAR',MSGLEVEL=1,PRTY=0,     1
```

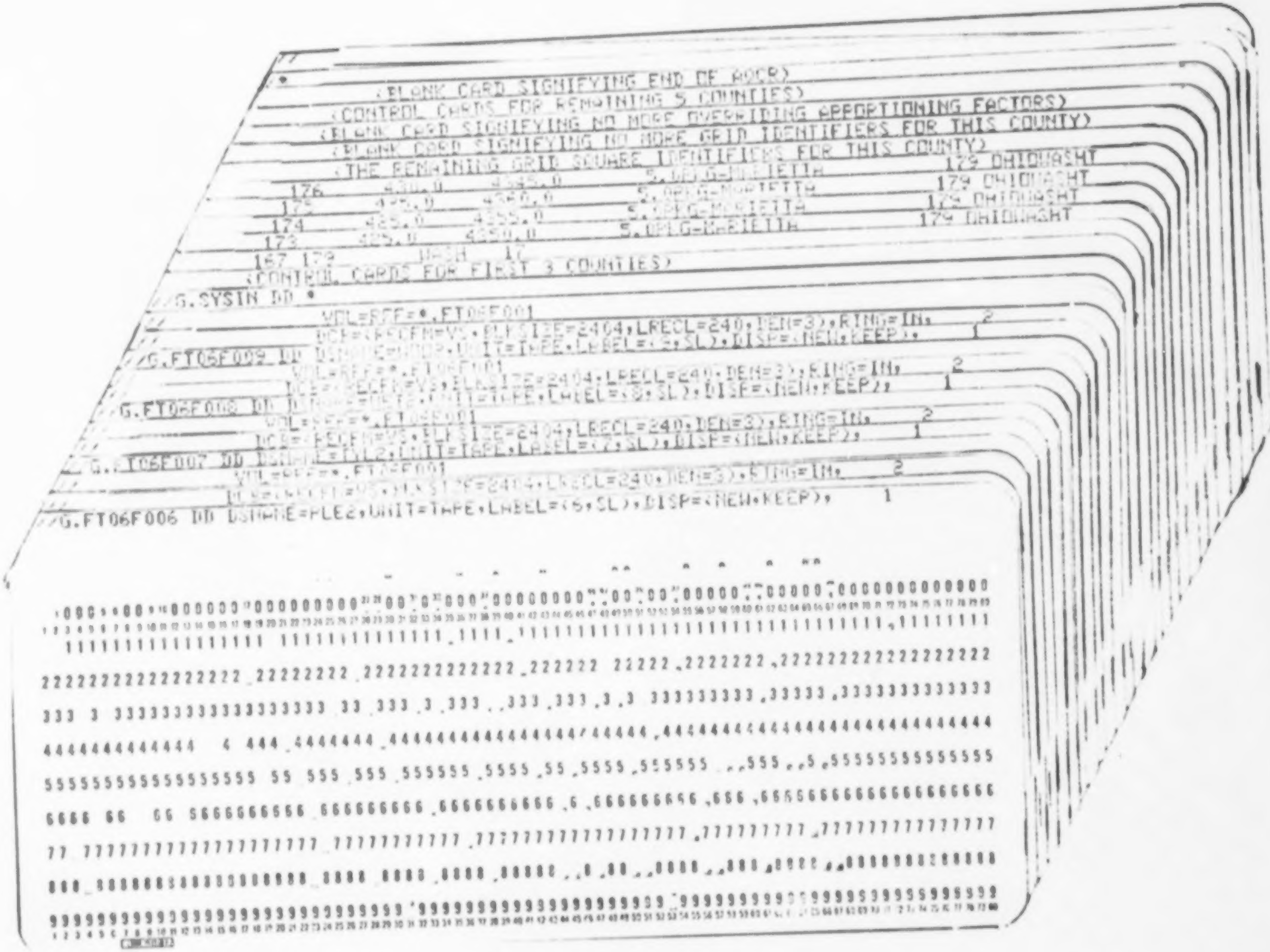
Figure 11. JCL and Input Data Cards for CAASE4



```
//              VOL=REF=*.FT06F001
//               DCB=(RECFM=VS,BLKSIZE=2404,LRECL=240,DEN=3),RING=IN,    2
//G.FT06F005 DD DSNAME=JAC2,UNIT=TAPE,LABEL=(5,SL),DISP=(NEW,KEEP),      1
//              VOL=REF=*.FT06F001
//               DCB=(RECFM=VS,BLKSIZE=2404,LRECL=240,DEN=3),RING=IN,    2
//G.FT06F004 DD DSNAME=WAS2,UNIT=TAPE,LABEL=(4,SL),DISP=(NEW,KEEP),      1
//              VOL=REF=*.FT06F001
//               DCB=(RECFM=VS,BLKSIZE=2404,LRECL=240,DEN=3),RING=IN,    2
//G.FT06F003 DD DSNAME=MDR2,UNIT=TAPE,LABEL=(3,SL),DISP=(NEW,KEEP),      1
//              VOL=REF=*.FT06F001
//               DCB=(RECFM=VS,BLKSIZE=2404,LRECL=240,DEN=3),RING=IN,    2
//G.FT06F002 DD DSNAME=MET2,UNIT=TAPE,LABEL=(2,SL),DISP=(NEW,KEEP),      1
//              VOLUME=SER=RED141
//               DCB=(RECFM=VS,BLKSIZE=2404,LRECL=240,DEN=3),RING=IN,    2
//G.FT06F001 DD DSNAME=ATH2,UNIT=TAPE,LABEL=(1,SL),DISP=(NEW,KEEP),      1
//  DISP=(OLD,KEEP)
//  DCB=(RECFM=FB,LRECL=512,BLKSIZE=512),SPACE=(TRK,(5,1)),               2
//G.FT05F001 DD DSN=GRDTE66,UNIT=DISK,VOL=SER=RTIEES,                     1
//              VOLUME=REF=*.FT04F001
//               DCB=(RECFM=FB,BLKSIZE=2970,LRECL=198,DEN=2),             2
//G.FT04F009 DD DSNAME=[illegible],UNIT=TAPE,LABEL=(9,SL),DISP=(OLD,KEEP), 1
//              VOLUME=REF=*.FT04F001
//               DCB=(RECFM=FB,BLKSIZE=2970,LRECL=198,DEN=2),             2
//G.FT04F008 DD DSNAME=WET2,UNIT=TAPE,LABEL=(8,SL),DISP=(OLD,KEEP),      1
```

Figure 11. (Continued)

252<



```
//
/*
      (BLANK CARD SIGNIFYING END OF AQCR)
    (CONTROL CARDS FOR REMAINING 5 COUNTIES)
    (BLANK CARD SIGNIFYING NO MORE OVERRIDING APPORTIONING FACTORS)
    (BLANK CARD SIGNIFYING NO MORE GRID IDENTIFIERS FOR THIS COUNTY)
    (THE REMAINING GRID SQUARE IDENTIFIERS FOR THIS COUNTY)
  176    430.0    4365.0          5.UPLG-MARIETTA            179 OHIOWASHT
  175    425.0    4360.0          5.UPLG-MARIETTA            179 OHIOWASHT
  174    425.0    4355.0          5.UPLG-MARIETTA            179 OHIOWASHT
  173    425.0    4350.0          5.UPLG-MARIETTA            179 OHIOWASHT
  167 179         WASH    17
  (CONTROL CARDS FOR FIRST 3 COUNTIES)
//G.SYSIN DD *
//             VOL=REF=*.FT06F001
//             DCB=(RECFM=VS,BLKSIZE=2404,LRECL=240,DEN=3),RING=IN,    2
//G.FT06F009 DD DSNAME=[illegible],UNIT=TAPE,LABEL=(9,SL),DISP=(NEW,KEEP),    1
//             VOL=REF=*.FT06F001
//             DCB=(RECFM=VS,BLKSIZE=2404,LRECL=240,DEN=3),RING=IN,    2
//G.FT06F008 DD DSNAME=[illegible],UNIT=TAPE,LABEL=(8,SL),DISP=(NEW,KEEP),    1
//             VOL=REF=*.FT06F001
//             DCB=(RECFM=VS,BLKSIZE=2404,LRECL=240,DEN=3),RING=IN,    2
//G.FT06F007 DD DSNAME=[illegible],UNIT=TAPE,LABEL=(7,SL),DISP=(NEW,KEEP),    1
//             VOL=REF=*.FT06F001
//             DCB=(RECFM=VS,BLKSIZE=2404,LRECL=240,DEN=3),RING=IN,    2
//G.FT06F006 DD DSNAME=PLE2,UNIT=TAPE,LABEL=(6,SL),DISP=(NEW,KEEP),    1
```

Figure 11. (Continued)

TABLE 8. TABLE OF INPUT VARIABLES, CAASE4

VARIABLE NAME	DEFINITION
ICNTY	Federal county code number for selected county
IREGN	Code number of selected AQCR
IPOLT	Code number of political subdivision of AQCR
CNTY1	Name of selected county
KZON	Primary UTM zone number
ITEST	Print switch option
EW	Direction to convert coordinates when AQCR straddles two UTM zone boundaries
ID	Area source grid square number
X	Lower left-hand X coordinate of the grid square
Y	Lower left-hand Y coordinate of the grid square
SIDE	Length of the side of the grid square
IDNUM	Area source grid square number for overriding weighting factor
ICAT	Source category number for overriding weighting factor (see Table 7)
WEIGHT	Overriding weighting factor for selected grid square-source category

TABLE 9. INPUT CARD LAYOUT, CAASE4

CARD TYPE	COLUMNS	FORMAT	VARIABLE NAME
1[*]	1-10	I10	ICNTY
	12-14	A3	IREGN
	16-20	I5	IPOLT
	22-25	A4	CNTY1
	26-30	I5	KZON
	31-35	I5	ITEST
	36-40	F5.0	EW
2[†]	1-10	I10	ID
	11-20	F10.0	X
	21-30	F10.0	Y
	31-40	F10.0	SIDE
3	A blank card signifying no more grids for this county.		
4[§]	1-10	I10	IDNUM
	11-20	I10	ICAT
	21-30	F10.0	WEIGHT
5[ξ]	A blank card signifying no more overriding weighting factors for this county.		

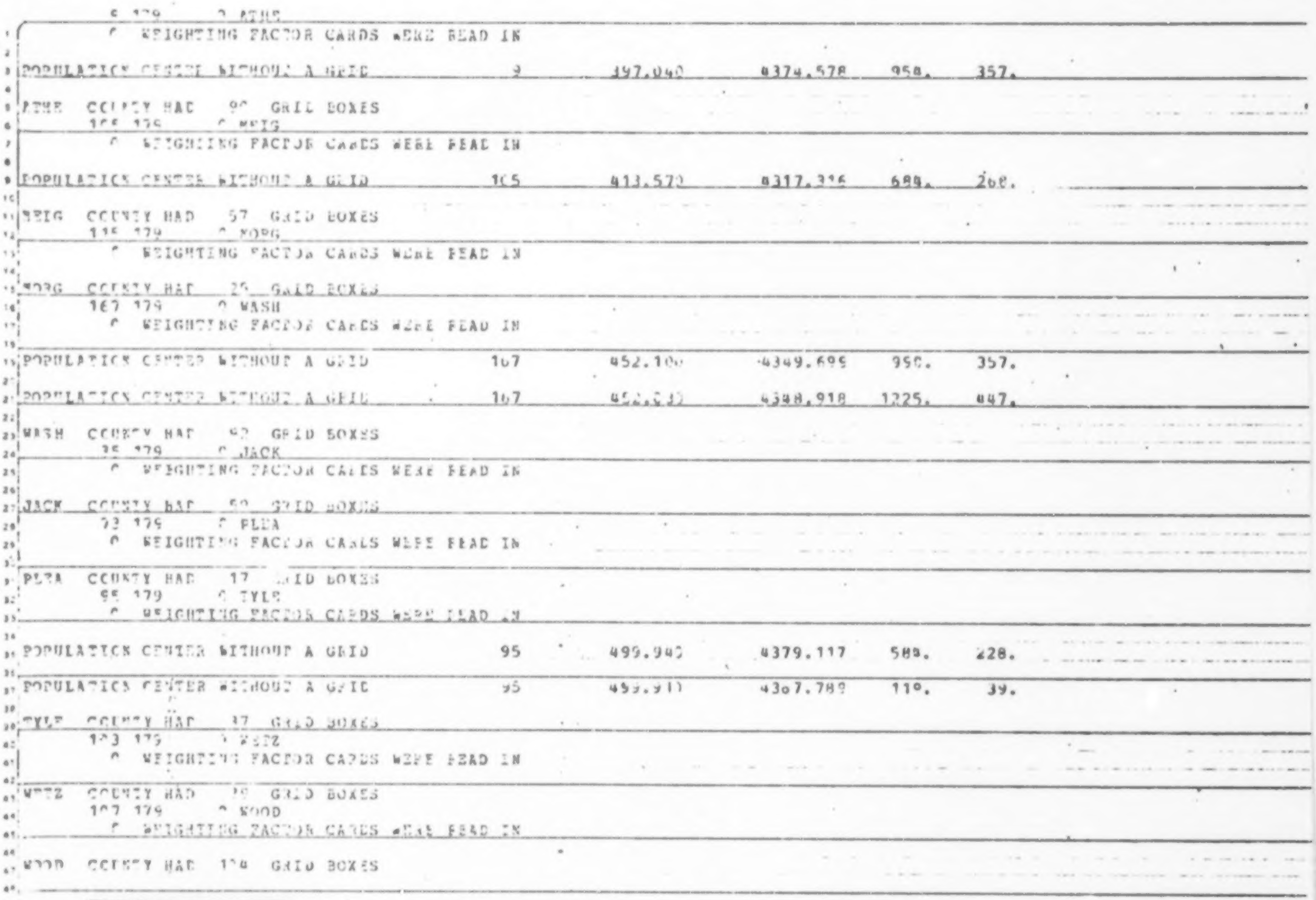
---

[*] CARD TYPE 1 is repeated for each county in the AQCR and follows CARD TYPE 5.

[†] CARD TYPE 2 is repeated for each grid square in the county.

[§] CARD TYPE 4 is repeated for each overriding weighting factor for the county's grid squares.

[ξ] A blank card follows CARD TYPE 5 when there are no more counties in the AQCR.



```
     5 179      0 ATHE
          0  WEIGHTING FACTOR CARDS WERE READ IN

POPULATION CENTER WITHOUT A GRID            9        397.040        4374.578   958.    357.

ATHE   COUNTY HAD    90  GRID BOXES
     165 179      0 MEIG
          0  WEIGHTING FACTOR CARDS WERE READ IN

POPULATION CENTER WITHOUT A GRID          165        413.570        4317.316   689.    268.

MEIG   COUNTY HAD    57  GRID BOXES
     115 179      0 MORG
          0  WEIGHTING FACTOR CARDS WERE READ IN

MORG   COUNTY HAD    25  GRID BOXES
     167 179      0 WASH
          0  WEIGHTING FACTOR CARDS WERE READ IN

POPULATION CENTER WITHOUT A GRID          167        452.100        4349.695   950.    357.

POPULATION CENTER WITHOUT A GRID          167        452.040        4348.918  1225.    447.

WASH   COUNTY HAD    92  GRID BOXES
      35 179      0 JACK
          0  WEIGHTING FACTOR CARDS WERE READ IN

JACK   COUNTY HAD    59  GRID BOXES
      73 179      0 PLEA
          0  WEIGHTING FACTOR CARDS WERE READ IN

PLEA   COUNTY HAD    17  GRID BOXES
      95 179      0 TYLE
          0  WEIGHTING FACTOR CARDS WERE READ IN

POPULATION CENTER WITHOUT A GRID           95        499.940        4379.117   588.    228.

POPULATION CENTER WITHOUT A GRID           95        499.910        4307.789   110.     39.

TYLE   COUNTY HAD    37  GRID BOXES
     103 179      0 WETZ
          0  WEIGHTING FACTOR CARDS WERE READ IN

WETZ   COUNTY HAD    29  GRID BOXES
     107 179      0 WOOD
          0  WEIGHTING FACTOR CARDS WERE READ IN

WOOD   COUNTY HAD   104  GRID BOXES
```

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Figure 12. Example of a Printout from CAASE4

6.0 CAASE5 PROGRAM

6.1 Program Description

The CAASE5 emissions calculation and apportioning program uses the apportioning factors output from CAASE4, the "fuels" totals from the NEDS file for each county, and the emissions factors for each emissions source category. It calculates the total emissions for the county, and then apportions ("SMEARS") them into the grid squares within the county according to the apportioning factors output from CAASE4. If so little is known about an emission source category that the associated emission factor has not been determined, that emission factor is set as zero in the CAASE5 program. If in the future an emission factor is determined for the source category, the zero is easily replaced by the new factor. The CAASE5 program calculates the same total emissions for a county as does the NEO3 program. The program uses subroutines READ1, OUTPT1, OUTPT2, and OUTPT3 which are described in other sections of this manual. Emissions factors, by source category and by pollutants are defined in FORTRAN DATA statements. In the FORTRAN source language code, the DATA statement named "EFHV" defines the emissions factors for highway vehicles, and the DATA statements "EMFAC1," "EMFAC2," "EMFAC3," "EMFAC4," and "EMFAC5" define the emission factors, scaled for units of fuel, that are used in calculating the emissions. Because some of the fuels are reported in tens of tons, hundreds of tons, thousands of gallons, etc., the emission factors include these scaling factors. For example, if 20 lbs. of suspended particles are produced by the burning of a ton of fuel, and the fuels totals are reported in tens of tons, then the emission factor would be multiplied by ten but, because the output is in tons of pollutant, the resulting number would then be divided by 2,000 which would yield a coefficient of .10, indicating that for every ten tons of fuel burned, .1 tons of particulates would be produced. If the units for reporting the fuel totals are ever changed, then the change would have to be reflected in these scaled emission factors.

When the CAASE5 program and its I/O subroutines were first written, the assumption had been made that 200 grid squares would adequately apportion emissions in any county being processed and that most counties could be adequately described with less than 100 grid squares. The total computer core storage requirements for a "job" was one of the terms included in the algorithm for computing computer charges on the system used to develop and apply the CAASE system; priority, volume of input/output, and the class of peripherals used were other terms. In early applications, the dimension terms in the storage arrays that were a function of the number of grid squares in a county were modified in the source language deck if any county being processed required more than 100 grid squares. The CAASE5 program was later modified, to its present form, whereby a five-statement "driving" program is used to set the dimensions for CAASE5 and its subroutines. CAASE5 is then, technically, a subroutine to the dimension setting "main" (driving) program; the main program has been compiled for each computer run using the variable "NDIM" as the maximum number of grid squares in any county being processed. In the processing of several AQCR's with a wide range of the number of grid squares within each county, a linear relationship was plotted of the actual core storage used by the load module (in thousands of bytes) and the maximum number of grid squares (denoted by the variable "NDIM") in any county being processed during a particular computer run; the regression line plotted in Figure 13 has been successfully used to estimate core storage requirements. As can be seen by inspecting Figure 13 the approximate core storage requirements, in K bytes, equals 0.45 times NDIM + 60, i.e. a slope of 0.45 and an intercept of 60K bytes. Figure 14 is an example of a run where the county being processed (Washington County, Ohio) contained 92 grid squares; the driving program dimensions which were a function of the number of grid squares were set to 100 and the variable NDIM passed these adjustable dimensions to CAASE5 and its subroutines through the "call argument lists."

The sequence of steps performed by the CAASE5 program is repeated for each county being processed and is described as follows: First, identification information for

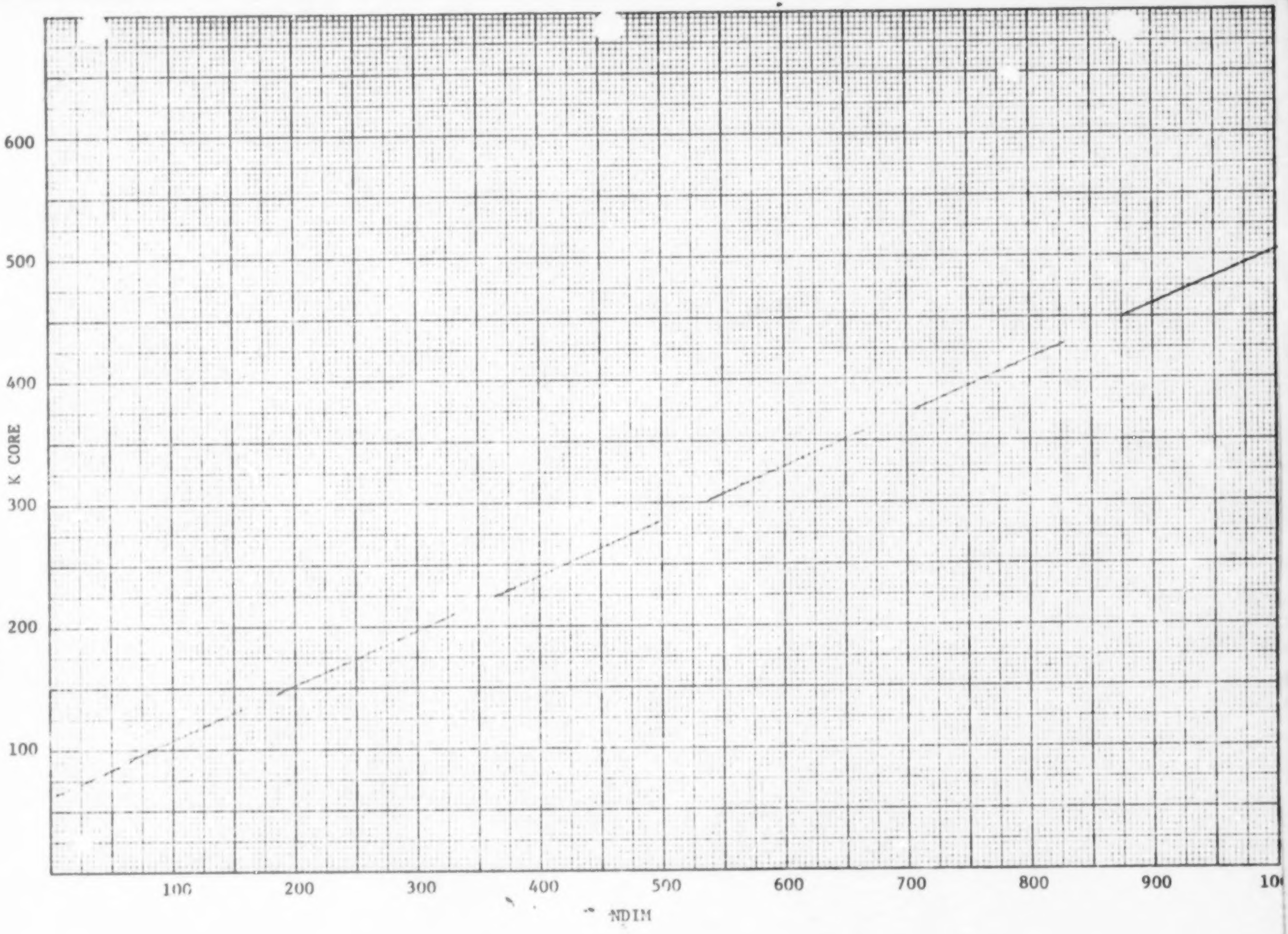


Figure 13. Plot of Core Storage Requirements Vs. the Number of Grid Squares in a County (NDIM)

the state, county, AQCR, and the number of grid squares in the county are read in from cards. Cards with labeling information are then read in and the subroutine READ1, which is described in Section 7.5, is called to read the "fuels" totals for the county from magnetic tape. If READ1 does not return an error condition, processing continues. The weighted apportioning factors are then read from a magnetic tape which was output from the CAASE4 program. The apportioning factor sums are then developed and become the denominators for apportioning each of the source categories. The program iterates ("loops") through the number of grid squares for the county being processed and through all of the "fuel" categories. For each fuel category, the number in each grid square is used as the numerator and the sum of all apportioning values, for all grid squares, for that category is used as the denominator. This fractional portion of the total "fuel" within the county is later apportioned to the grid square. For example, if there are 50 grid squares within the county being processed, the first fuel category (residential fuel-anthracite coal) is apportioned into the 50 grid squares based on the fractional apportioning value assigned to each grid square as explained in Sections 1.3, 5.1, and 9.0. A summation of these fractions, for all grid squares, for each category, yields unity, i.e., summing all of the numbers for each grid square within the county for "Fuel Category 1" will equal the first denominator. After the fuels have been apportioned for all categories, the subroutine OUTPT1 is called which causes the printing of tables; OUTPT1 is described in Section 7.6. The CAASE5 program then calculates total emissions for each of the five pollutants of interest (SP, SO_2, NO_x, HC, and CO) for each of the fuel categories. The mobile source categories are dealt with in the same way that the EPA NEO3 program calculates them -- measured vehicle miles by speed categories are used, if available, and the ratios for vehicle classes are calculated using estimates of miles per gallon of fuel used for each of the different vehicle classes. The emissions are then apportioned one pollutant at a time to limit the core storage requirements. The total emissions for all fuel categories, for the county, is summed and printed for comparison with the total emissions recorded on the NEDS USER'S file. The five emissions for all fuel categories are summed for each grid square and saved for the IPP cards which will be output later using the OUTPT3 subroutine described in Section 7.8 of this manual. The apportioned emissions are printed in tabular form using the subroutine OUTPT2 which is described in Section 7.7 of this manual. After apportioned emissions are output for all five pollutants the IPP cards are produced by calling the OUTPT3 subroutine. A binary tape is written containing all table entries. Flow charts of the program logic of CAASE5 and its subroutines appear in Appendix E.

6.2 Job Control Language (JCL) and Deck Setup

An example of the deck setup configuration is illustrated in Figure 2. The JCL cards associated with the example are illustrated in Figure 14. The JCL configuration illustrated assumes the following:

a. The program is in object deck form except for the dimension setting driving program.

b. The punched cards assigning values to the input variables are in the job input stream.

c. Apportioning factor data are on magnetic tape, reel number RED141, output from CAASE4 as file number four.

d. The fuels totals for the county being processed are on magnetic tape, reel number ADC519, and represent a stripped file from the NEDS emissions data base.

e. Output of apportioned emissions and fuels are output on the printer file and are written on magnetic tape, reel number RED143, as file number four.

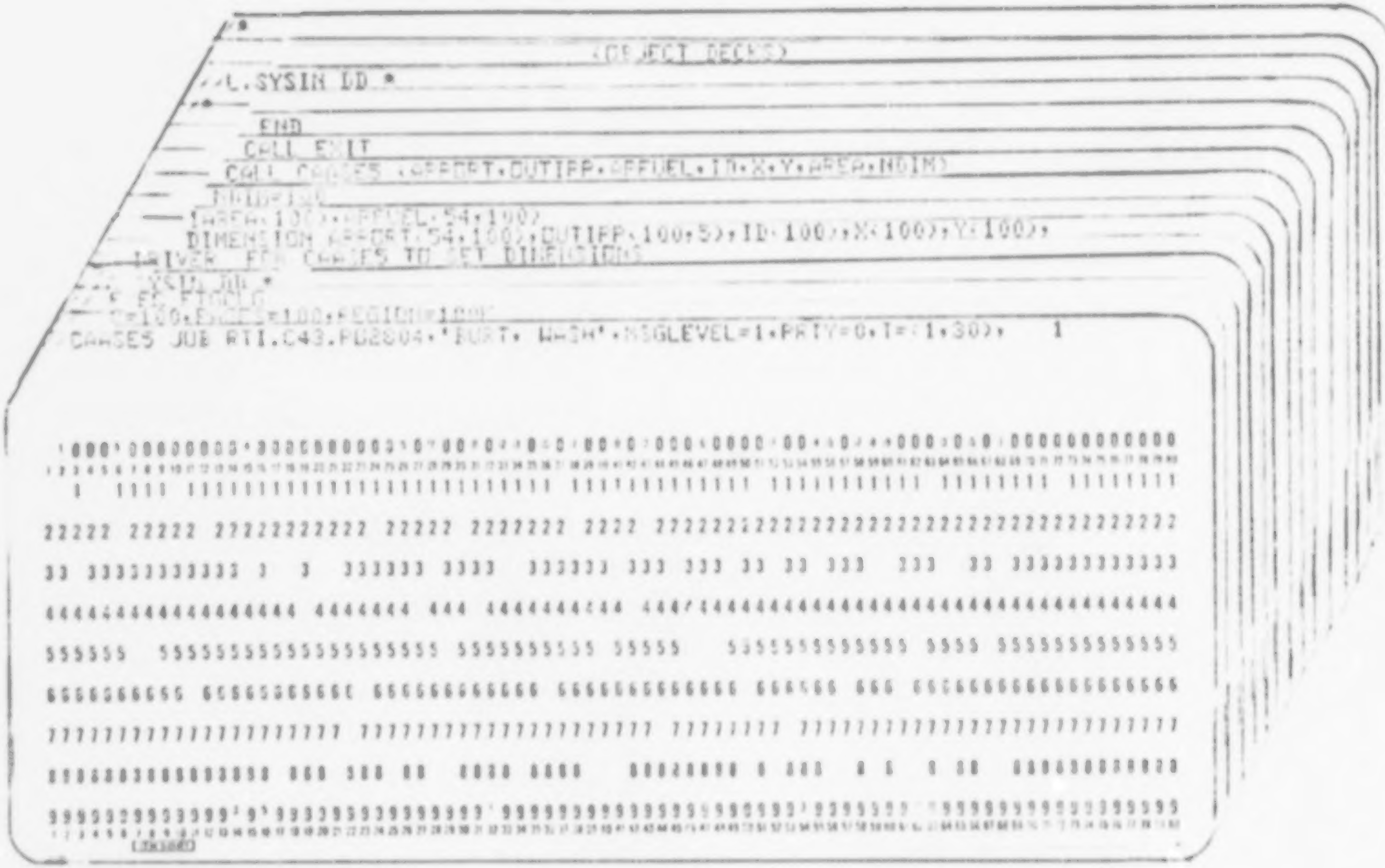
6.3 Input Information

The punched card input variables appear in Table 10. The state, county, and AQCR numbers are input. The number of grid squares for the county being processed, the county name, and the EPA county number are also input. The EPA assignment of county numbers is not the same as the Federal county's assignment on the census tapes; therefore, when referring to the county number, the Federal county code number is used for census data, and the EPA county number is used when searching the "fuels" total tape.

The end of processing for a particular computer run is signaled by a "0" in the input card field specifying the number of grid squares within a county (the variable "NAREAS"). The subroutine READ1 is used for reading the "fuels" totals tape. The grid square identification, the county, the apportioning factor for each grid square-source category combination (a 54 by N array where N is the number of grid squares within the county), the UTM coordinates of the lower left-hand corner of each grid square, and its side length, are input from a binary tape created in CAASE4. The input card layout is described in Table 11.

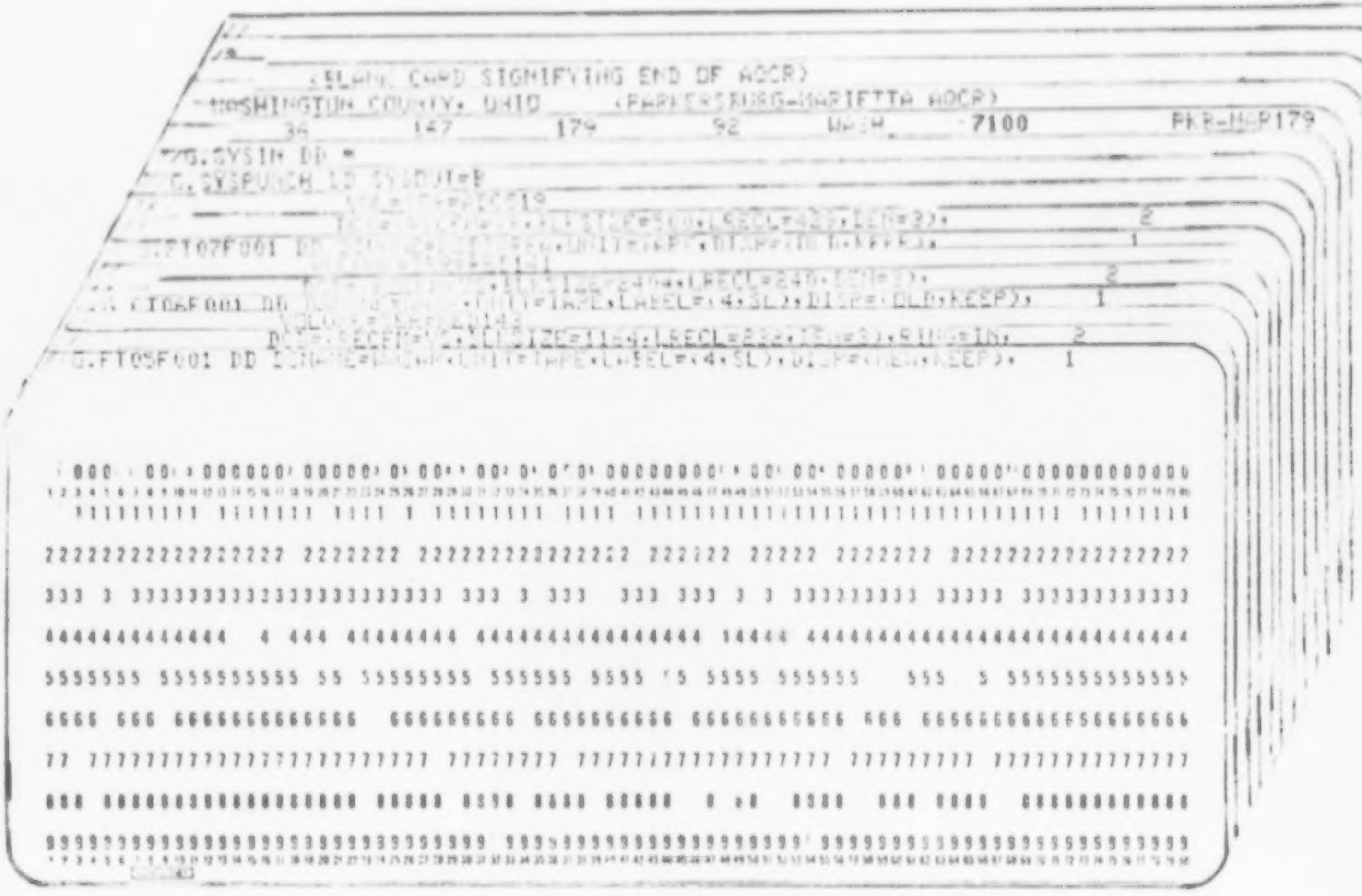
6.4 Output Information

Output from the CAASE5 program includes diagnostic messages, error messages, tables of apportioned fuels, tables of apportioned emissions for each of the five pollutants of interest, an IPP card deck, and a binary tape containing the arrays used in outputting the tables. As explained in Sections 7.6, 7.7, and 7.8 the apportioned emissions and the apportioned fuels are output as tables where OUTPT1 output tables are for apportioned fuels, OUTPT2 tables are apportioned emissions (and separate tables are produced for each of the five pollutants). OUTPT3 also produces the card images in the IPP input format for the five pollutants. A binary tape is produced of the apportioned fuels, emissions, and IPP card variables so that they are available for any additional computer applications which may arise. Figures 15 through 19 are examples of tables of apportioned fuels for Washington County, Ohio; five tables are always necessary to output apportioned fuels for all source categories. Apportioned emissions tables are output in a format similar to the apportioned fuels tables, and Figure 20 is an example of the first page of the first table for particulate emissions for Washington County, Ohio. Figure 21 is an example of the table printed by the CAASE5 program to depict the contribution of each source category to the county total for each pollutant; pollutants numbered 1 through 5 represent SP, SO_2, NO_x, HC, and CO, respectively, and each table is read row-wise for the 54 categories; the last line in the figure appears in the output on a separate page (it was placed in the figure to conserve space) and represents the total particulate emissions for the county for all area source categories and was compared with the total area source emissions from the NEDS USER'S file computed by the EPA NEO3 program during the application of the CAASE system. The county total for each pollutant is output just prior to the output of the apportioned emissions tables for that pollutant. Five tables for apportioned "fuels" are output with a maximum of 45 grid squares on each page, and five tables are output for each of the five pollutants with a maximum of 45 grid squares on each page. Information output on IPP cards is also printed; see Figure 22 for an example.



```
/*
                    (OBJECT DECKS)
//L.SYSIN DD *
/*
      END
      CALL EXIT
      CALL CAASES (AFFDRT,OUTIFP,AFFUEL,ID,X,Y,AREA,NDIM)
      NDIM=100
     1AREA(100),AFFUEL(54,100)
      DIMENSION AFFDRT(54,100),OUTIFP(100,5),ID(100),X(100),Y(100),
C DRIVER FOR CAASES TO SET DIMENSIONS
//SYSIN DD *
// EXEC FTGCLG
// C=100,PAGES=100,REGION=100K
//CAASES JOB RTI.C43.PD2804,'BURT, WASH',MSGLEVEL=1,PRTY=0,T=(1,30),   1
```

Figure 14. JCL and Input Data Cards for CAASE5



```
//
/*
       (BLANK CARD SIGNIFYING END OF ADCR)
WASHINGTON COUNTY, OHIO      (PARKERSBURG-MARIETTA ADCR)
      36        147        179        92        WASH      7100            PKR-MAP179
//G.SYSIN DD *
//G.SYSPUNCH DD SYSOUT=B
//             [illegible]
//             [illegible]BLKSIZE=[illegible],LRECL=[illegible],DEN=2),                   2
//G.FT07F001 DD [illegible],UNIT=[illegible],DISP=(OLD,KEEP),                              1
//             [illegible]
//             [illegible]BLKSIZE=240[illegible],LRECL=240,DEN=2),                       2
//G.FT06F001 DD [illegible],UNIT=TAPE,LABEL=(4,SL),DISP=(OLD,KEEP),                       1
//             VOLUME=SER=[illegible]
//             DCB=(RECFM=[illegible],BLKSIZE=1164,LRECL=[illegible],DEN=3),RING=IN,     2
//G.FT05F001 DD DSNAME=[illegible],UNIT=TAPE,LABEL=(4,SL),DISP=(NEW,KEEP),               1
```

Figure 14. (Continued)

TABLE 10. TABLE OF INPUT VARIABLES, CAASE5

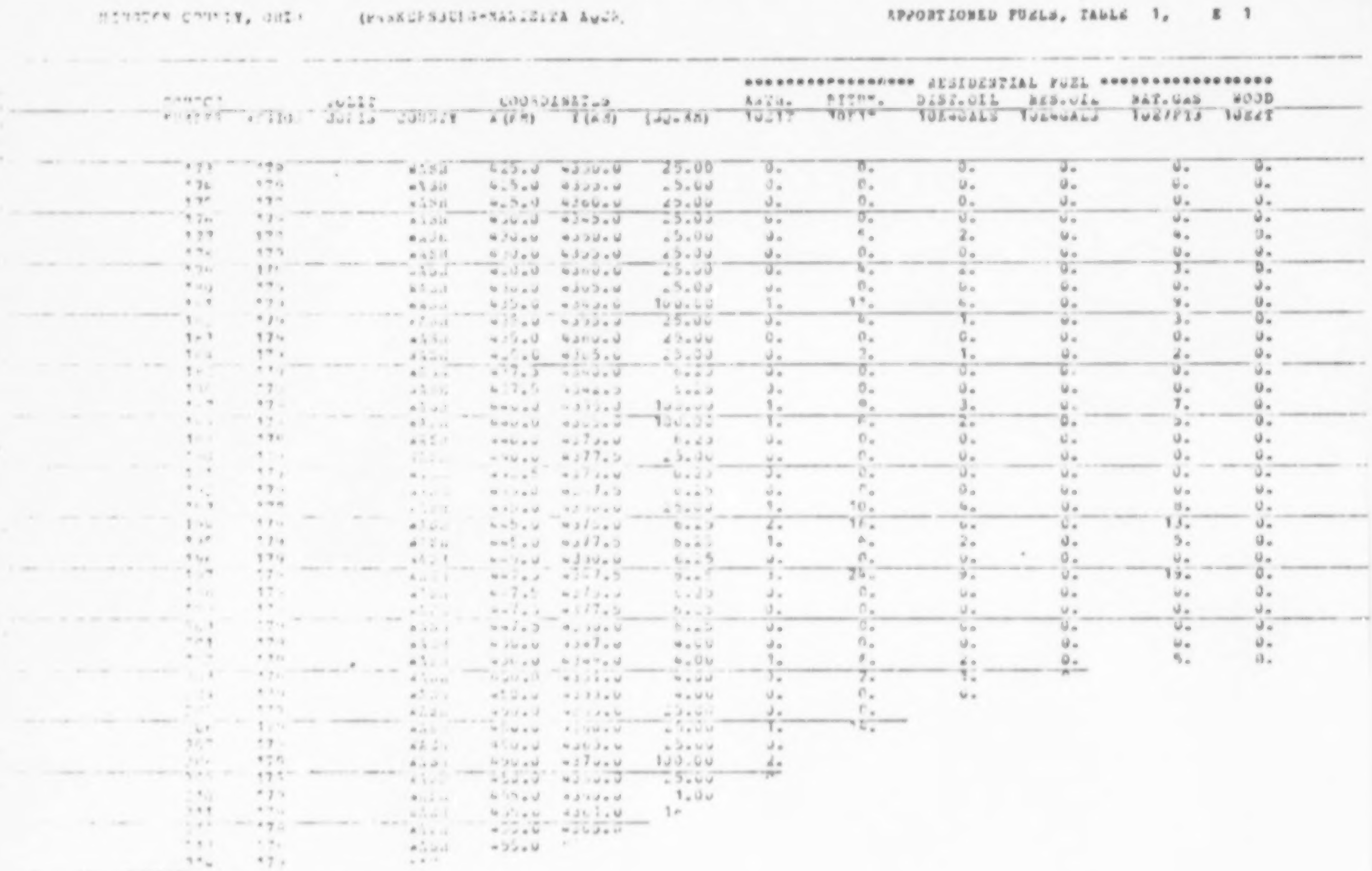
VARIABLE NAME	DEFINITION
XSTATE	EPA state code of selected state
ICNTY	Federal county code of selected county
XAQCR	Code number of selected Air Quality Control Region
NAREAS	Number of grid squares in selected county
CNTY	Name of selected county
KOUNTY	EPA county code of selected county
IPOLIT	Political subdivision of selected Air Quality Control Region
IREGN	Code number of selected Air Quality Control Region
HDG	Page heading including name of county and state of interest

TABLE 11. INPUT CARD LAYOUT, CAASE5

CARD TYPE	COLUMNS	FORMAT	VARIABLE NAME
1*	1-10	F10.0	XSTATE
	11-20	I10	ICNTY
	21-30	F10.0	XAQCR
	31-40	I10	NAREAS
	47-50	A4	CNTY
	51-60	I10	KOUNTY
	70	A1	IPOLIT
	78-80	A3	IREGN
2*	1-80	20A4	HDG
3	A blank card used only when there are no more counties in the AQCR to be processed during the computer run.		

---

*CARD TYPES 1 and 2 make a set which is re,eated for each county in the AQCR.



```
APPORTIONED FUELS, TABLE 1,
          COORDINATES          ****** RESIDENTIAL FUEL ******
                               DIST.OIL   RES.OIL   NAT.GAS   WOOD
```

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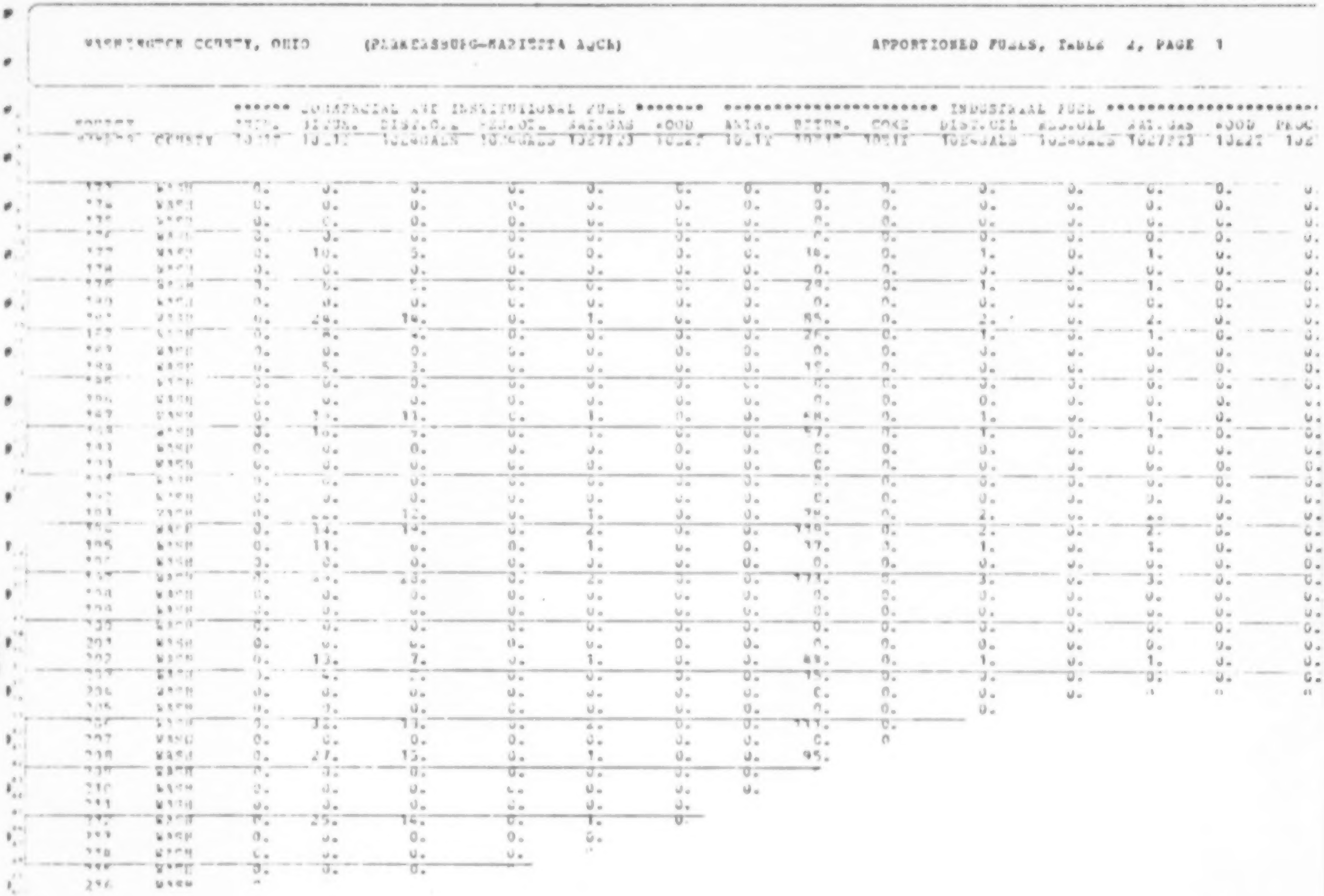
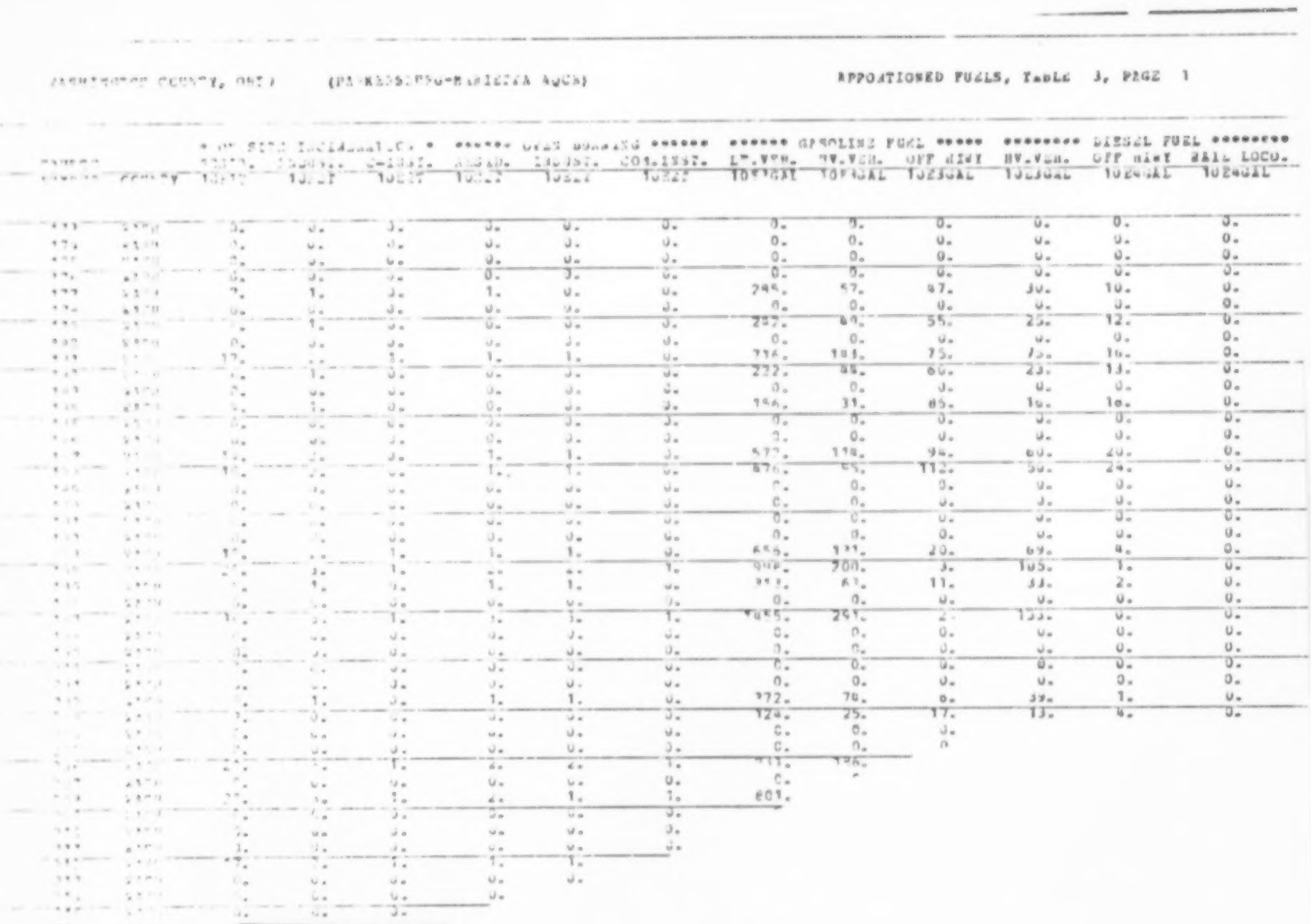
Figure 15. Example of CAASES Output Table 1, Apportioned Fuels



WASHINGTON COUNTY, OHIO (PARKERSBURG-MARIETTA AQCR) APPORTIONED FUELS, TABLE 2, PAGE 1

Figure 16. Example of CAASE5 Output Table 2, Apportioned Fuels



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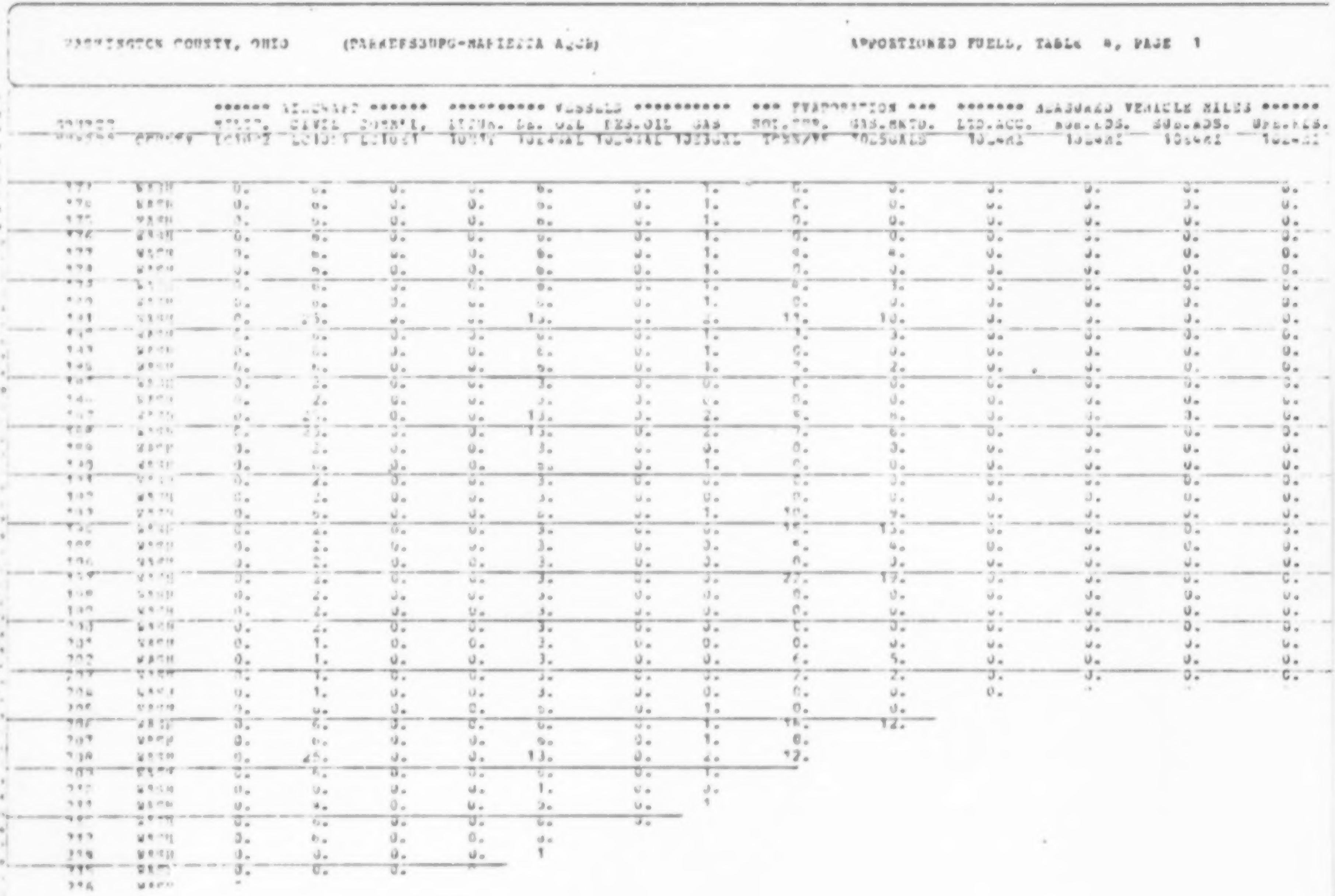
best available copy.

Figure 17. Example of CAASE5 Output Table 3, Apportioned Fuels



```
WASHINGTON COUNTY, OHIO     (PARKERSBURG-MARIETTA AQCR)                    APPORTIONED FUELS, TABLE 4, PAGE 1

                  ****** AIRCRAFT ******  ********** VESSELS **********  *** EVAPORATION ***  ******* MEASURED VEHICLE MILES ******
SOURCE            MILIT.  CIVIL  COMM'L,  BITUM.  DS. OIL  RES.OIL  GAS  SOL.EVP.  GAS.MKTG.  LTD.ACC.  RUR.RDS.  SUB.RDS.  URB.RDS.
```

Figure 18. Example of CAASES Output Table 4, Apportioned Fuels

```
WASHINGTON COUNTY, OHIO      (PARKERSBURG-MARIETTA AQCR)                          APPORTIONED FUELS, TABLE  5, PAGE  1

                   [illegible]  [illegible] AIR  CONSTR.   ROCK HAND.  * FOREST FIRES *    SLASH BURNING     FROST CONTROL           COAL REF. BURN.
 [illegible]       [illegible]  [illegible]     LAST ACR  AND STOR.  AN.ACRES  QUANT.   AN.ACRES  QUANT.   ORCH.     DAYS   STRUC.   BANK     NUMBER
 GRID  COUNTY      [illegible]   LTO CYC       10**3ACR    10**3T              T/ACR              T/ACR    HEAT.     FIRED  FIRES    SIZE      PER
                                                                                                           1022      DY/YR   #/YR   1022YD3   YEAR

[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   3.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   3.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   8.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   3.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   2.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   6.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   5.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   3.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   7.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  11.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   4.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.  17.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   6.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.   0.
[illegible] [illegible]   0.   0.   0.
[illegible] [illegible]
```

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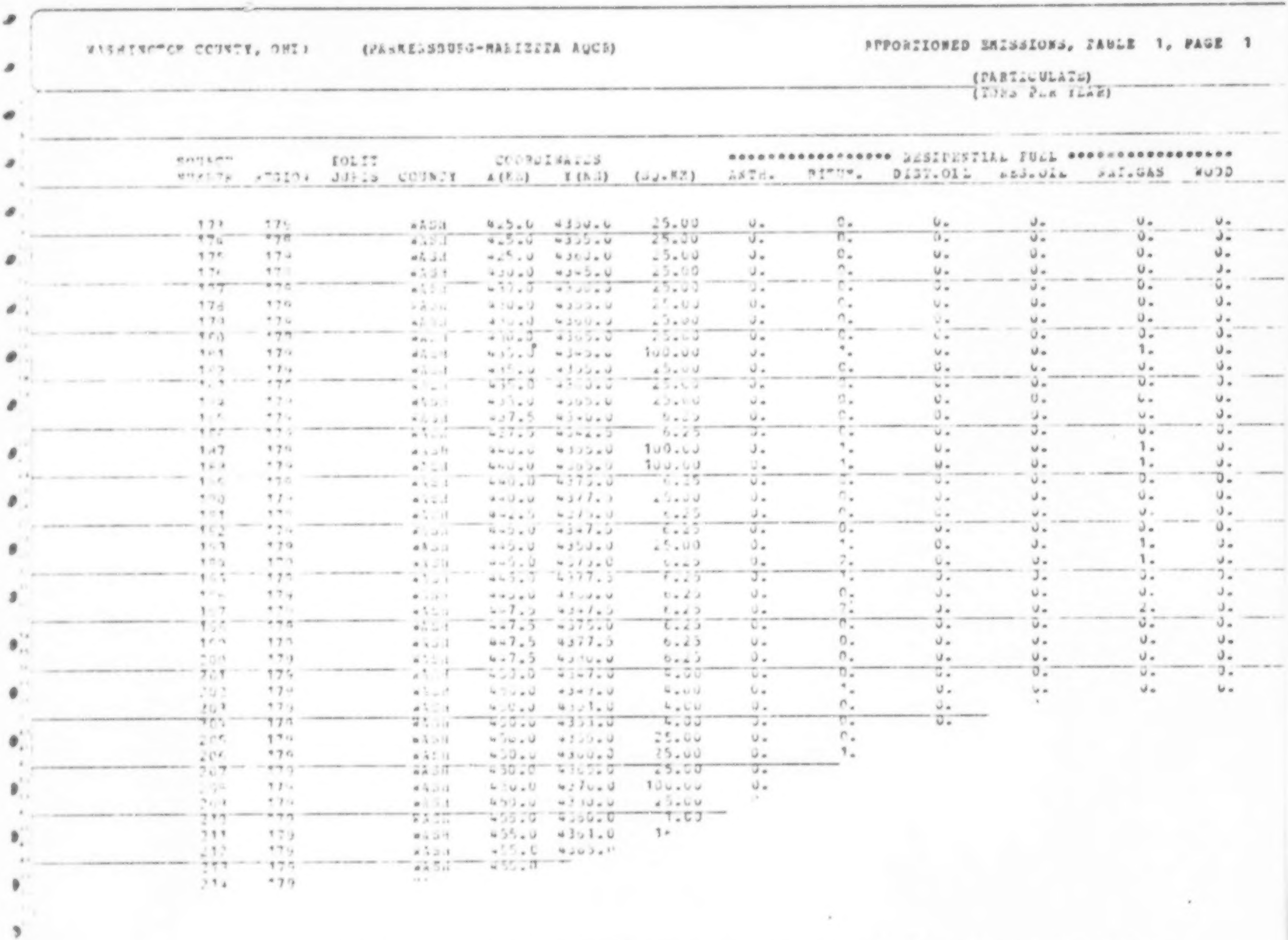
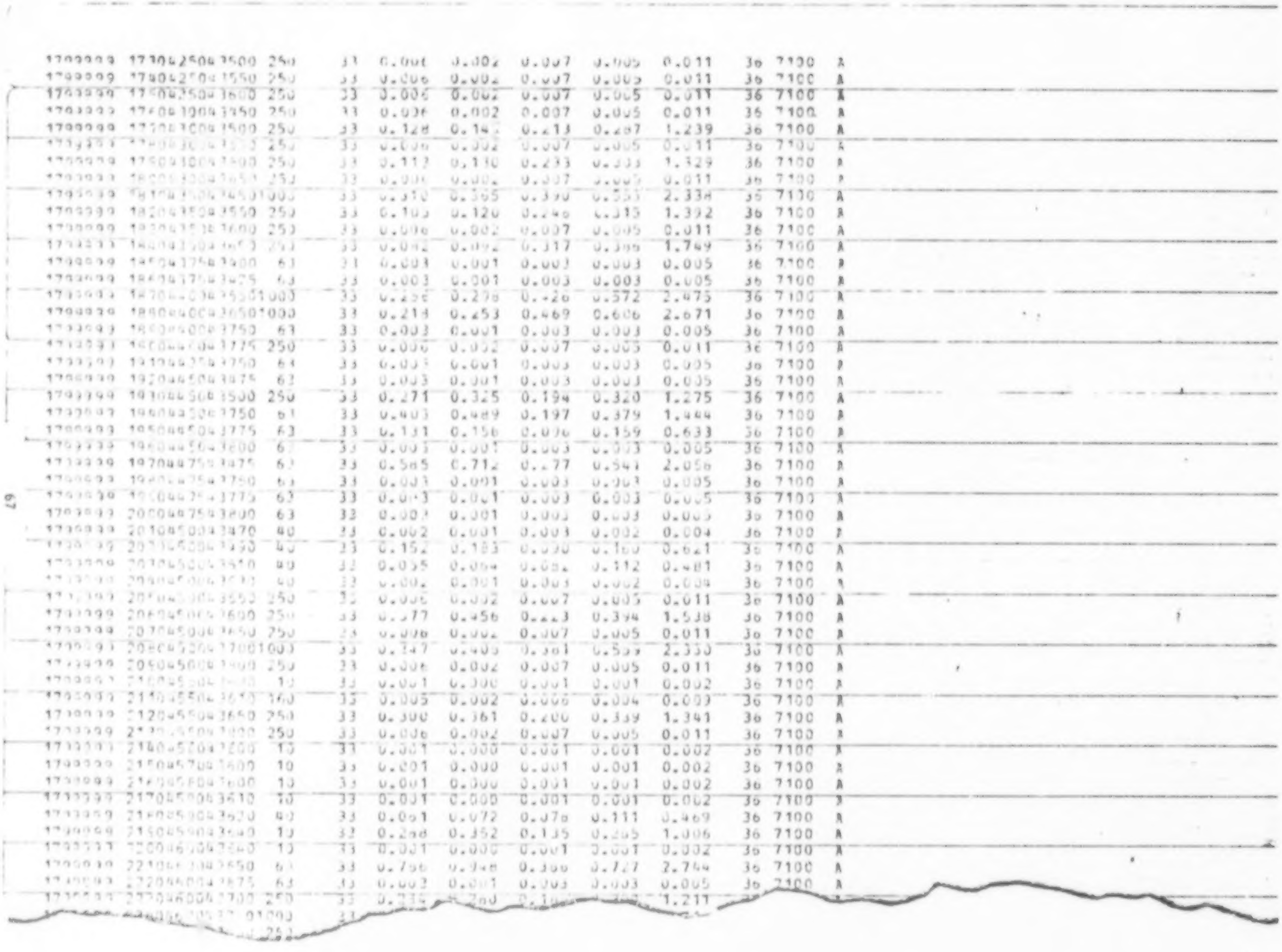
Figure 19. Example of CAASE5 Output Table 5, Apportioned Fuels



```
WASHINGTON COUNTY, OHIO     (PARKERSBURG-MARIETTA AQCR)                          APPORTIONED EMISSIONS, TABLE  1, PAGE  1
                                                                                          (PARTICULATE)
                                                                                          (TONS PER YEAR)

   SOURCE          POLIT             COORDINATES              ****************** RESIDENTIAL FUEL *****************
   NUMBER  REGION  JURIS  COUNTY   X(KM)    Y(KM)   (SQ.KM)   ANTH.    BITUM.   DIST.OIL   RES.OIL   NAT.GAS   WOOD
```

Figure 20. Example of CAASE5 Output Table 1, Apportioned Emissions, Particulates

```
[illegible] BY SOURCE CATEGORY FOR POLLUTANT NUMBER    1
  [illegible]  13.500   7.400    0.0        25.030   3.003    0.0       786.089   73.725    0.0
    1.13[illegible] 0.0  0.0     2375.163    0.0      3.343    0.0         8.320    0.0      0.0
  [illegible]  42.000  [illegible] 11.230   20.700   10.400    0.0         0.0      6.308    0.0
  [illegible]   0.47[illegible] 0.0  1.227   0.0      0.0     55.375       0.0      3.243    0.0
    0.0         0.0  [illegible]  0.0       40.137    0.0      0.0         0.0      0.0      0.0
    0.0         0.0     0.0       0.0

[illegible] BY SOURCE CATEGORY FOR POLLUTANT NUMBER    2
    0.0   [illegible] [illegible] 0.0   [illegible]  0.100    0.0   [illegible]  27.193    0.0
    3.335       0.0     0.0    2301.743    0.0      3.337    0.0         3.768    0.0      0.0
    4.077 [illegible] [illegible] [illegible] 1.750 [illegible] 0.0      0.0      6.307    0.0
  [illegible] [illegible] 0.0 [illegible]  0.0      0.0    14[illegible]  0.0     0.130    0.0
    0.0         0.0  [illegible]  0.0       35.694    0.0      0.0         0.0      0.0      0.0
    0.0         0.0     0.0       0.0

[illegible] BY SOURCE CATEGORY FOR POLLUTANT NUMBER    3
    3.540 [illegible]  7.[illegible] 0.0    63.500    2.000    0.0        39.666  11[illegible]  0.0
   15.[illegible] 0.0   0.0      184.160    0.0     14.100    0.0        87.700    0.0      0.0
  [illegible]   7.000   1.730     11.720    10.500    5.900    0.0         0.0    953.736    0.0
  [illegible] [illegible] 0.0      1.110     0.0      0.0    160.125       0.0      5.250    0.0
    0.0         0.0  [illegible]  0.0      826.823    0.0      0.0         0.0      0.0      0.0
    0.0         0.0     0.0       0.0

[illegible] BY SOURCE CATEGORY FOR POLLUTANT NUMBER    4
  [illegible]  13.500   1.720     0.0       10.900    0.400    0.0     [illegible]  5.785    0.0
    1.[illegible] 0.0   1.0       12.920     0.0      0.705    0.0     [illegible]  0.0      0.0
  [illegible]  15.000   3.500     66.100    57.500   42.100    0.0         0.0   [illegible]  0.0
  [illegible] [illegible] 0.0      5.643     0.0      0.0    110.750       0.0     16.590  309.030
  741.510       0.0  1857.175     0.0     1569.643    0.0      0.0         0.0      0.0      0.0
    0.0         0.0     0.0       0.0

[illegible] BY SOURCE CATEGORY FOR POLLUTANT NUMBER    5
  [illegible] [illegible] [illegible] 0.0   27.400    0.400    0.0        26.496    0.383    0.0
  [illegible]   0.0     0.0       24.[illegible] 0.0  0.347    0.0     [illegible]  0.0      0.0
  [illegible]  70.100  17.000    165.750   144.750   55.250    0.0         0.0   2446.704    0.0
  [illegible]   7.150   0.0       31.104     0.0      0.0    155.050       0.0     90.900    0.0
    0.0         0.0  [illegible]  0.0     [illegible] 0.0      0.0         0.0      0.0      0.0
    0.0         0.0     0.0       0.0

[illegible] [illegible] OF TOTAL [illegible]       1756.954
```



```
1799999 1730425043500 250     33  0.006  0.002  0.007  0.005  0.011   36 7100  A
1799999 1740425043550 250     33  0.006  0.002  0.007  0.005  0.011   36 7100  A
1799999 1750425043600 250     33  0.006  0.002  0.007  0.005  0.011   36 7100  A
1799999 1760410043350 250     33  0.006  0.002  0.007  0.005  0.011   36 7100  A
1799999 1770410043500 250     33  0.128  0.147  0.213  0.287  1.239   36 7100  A
1799999 1780430043550 250     33  0.006  0.002  0.007  0.005  0.011   36 7100  A
1799999 1790410043600 250     33  0.112  0.130  0.233  0.333  1.329   36 7100  A
1799999 1800430043650 250     33  0.006  0.002  0.007  0.005  0.011   36 7100  A
1799999 18104350434501000     33  0.310  0.365  0.390  0.551  2.338   36 7100  A
1799999 1820435043550 250     33  0.103  0.120  0.246  0.315  1.392   36 7100  A
1799999 1830435043600 250     33  0.006  0.002  0.007  0.005  0.011   36 7100  A
1799999 1840435043650 250     33  0.042  0.092  0.317  0.386  1.749   36 7100  A
1799999 1850437543500  63     33  0.003  0.001  0.003  0.003  0.005   36 7100  A
1799999 1860437543475  63     33  0.003  0.001  0.003  0.003  0.005   36 7100  A
1799999 18704400435501000     33  0.256  0.298  0.426  0.572  2.475   36 7100  A
1799999 18804400436501000     33  0.218  0.253  0.469  0.606  2.671   36 7100  A
1799999 1890440043750  63     33  0.003  0.001  0.003  0.003  0.005   36 7100  A
1799999 1900440043775 250     33  0.006  0.002  0.007  0.005  0.011   36 7100  A
1799999 1910442543750  63     33  0.003  0.001  0.003  0.003  0.005   36 7100  A
1799999 1920445043875  63     33  0.003  0.001  0.003  0.003  0.005   36 7100  A
1799999 1930445043500 250     33  0.271  0.325  0.194  0.320  1.275   36 7100  A
1799999 1940445043750  61     33  0.403  0.489  0.197  0.379  1.444   36 7100  A
1799999 1950445043775  63     33  0.131  0.156  0.096  0.159  0.633   36 7100  A
1799999 1960445043800  63     33  0.003  0.001  0.003  0.003  0.005   36 7100  A
1799999 1970447543475  63     33  0.585  0.712  0.477  0.541  2.056   36 7100  A
1799999 1980447543750  63     33  0.003  0.001  0.003  0.003  0.005   36 7100  A
1799999 1990447543775  63     33  0.003  0.001  0.003  0.003  0.005   36 7100  A
1799999 2000447543800  63     33  0.003  0.001  0.003  0.003  0.005   36 7100  A
1799999 2010450043470  40     33  0.002  0.001  0.003  0.002  0.004   36 7100  A
1799999 2020450043490  40     33  0.152  0.183  0.090  0.160  0.621   36 7100  A
1799999 2030450043510  40     32  0.055  0.064  0.062  0.112  0.481   36 7100  A
1799999 2040450043630  40     33  0.002  0.001  0.003  0.002  0.004   36 7100  A
1799999 2050450043550 250     33  0.006  0.002  0.007  0.005  0.011   36 7100  A
1799999 2060450043600 250     33  0.377  0.456  0.223  0.394  1.538   36 7100  A
1799999 2070450043650 250     33  0.006  0.002  0.007  0.005  0.011   36 7100  A
1799999 20804520437001000     33  0.347  0.405  0.381  0.539  2.330   36 7100  A
1799999 2090450043800 250     33  0.006  0.002  0.007  0.005  0.011   36 7100  A
1799999 2100455043600  10     33  0.001  0.000  0.001  0.001  0.002   36 7100  A
1799999 2110455043650 360     33  0.005  0.002  0.006  0.004  0.009   36 7100  A
1799999 2120455043650 250     33  0.300  0.361  0.200  0.339  1.341   36 7100  A
1799999 2130455043800 250     33  0.006  0.002  0.007  0.005  0.011   36 7100  A
1799999 2140452043200  10     33  0.001  0.000  0.001  0.001  0.002   36 7100  A
1799999 2150457043600  10     33  0.001  0.000  0.001  0.001  0.002   36 7100  A
1799999 2160458043600  10     33  0.001  0.000  0.001  0.001  0.002   36 7100  A
1799999 2170459043610  10     33  0.001  0.000  0.001  0.001  0.002   36 7100  A
1799999 2180459043620  40     33  0.061  0.072  0.078  0.111  0.469   36 7100  A
1799999 2190459043640  10     32  0.288  0.352  0.135  0.265  1.006   36 7100  A
1799999 2200460043640  10     33  0.001  0.000  0.001  0.001  0.002   36 7100  A
1799999 2210460043650  63     33  0.796  0.948  0.300  0.727  2.744   36 7100  A
1799999 2220460043675  63     33  0.003  0.001  0.003  0.003  0.005   36 7100  A
1799999 2230460043700 250     33  0.335  0.280  0.10          1.211
        22406 20537 01000     33
                          250
```

Figure 22. Example of CAASES IPP Card Output

7.0 SUBROUTINE DESCRIPTIONS

7.1 CED009 Subroutine

7.1.1 Subroutine Description

The CED009 routine is used for the conversion of coordinates expressed in latitude and longitude to Universal Transverse Mercator (UTM) coordinates and was obtained from the Mathematics and Computation Laboratory, National Resource Evaluation Center; it is described in NREC Technical Manual No. 187, dated July 1966. The program will convert coordinates worldwide. CED009, as originally received, used five spheroid models which were (1) International; (2) Clarke, 1866; (3) Clarke, 1880; (4) Everest; and (5) Bessel. Tables of coefficients necessary for the conversion equations are contained in a FORTRAN BLOCK DATA Subroutine. In order to conserve computer core storage requirements, and because the standard spheroid used in the United States for dispersion modeling is the Clarke 1866, the routine has been modified to deal only with the Clarke 1866 spheroid. The BLOCK DATA Subroutine was modified to remove all tables of coefficients which were not related to the Clarke 1866 spheroid. The routine will convert geodetic latitudes from 80° south of the Equator to 80° north of the Equator, with those south of the Equator being considered negative. The routine will convert any longitude from 180° west to 180° east of Greenwich, with those west of Greenwich being considered negative; therefore, the CAASE calling program, CAASE1, sets the longitudes from the MED-X census data tapes to a negative value because all of the AQCR's lying within the contiguous United States have west longitudes. Input variables to this subroutine are communicated through the arguments in the "calling list" except for the tables of coefficients which are communicated through FORTRAN labeled COMMON and are set in the BLOCK DATA Subroutine. All output is through the subroutine "call argument list." The routine, as received was coded in FORTRAN for the Control Data CDC 3600 as single precision; however, because the CDC 3600 uses a computer word containing 60 binary bits and because the routine was to be run on an IBM 370/165 system, where a single precision FORTRAN word contains 32 binary bits, all calculations involving numbers with more than six significant decimal digits were modified to use double precision, thereby yielding a FORTRAN word of 64 binary bits. The coefficients for the conversion equations in the BLOCK DATA Subroutine were also converted to double precision for the IBM 370 version. CED009 permits the entry of the geodetic location in radians or seconds with two different scaling factors for each. For consistency, the calling program, CAASE1, calls CED009 with latitude and longitude in seconds scaled by 10^5.

7.1.2 Inputs to Subroutine

Inputs through the "call argument list" include longitude, latitude, and an indicator of longitude and latitude units. Latitudes are expressed as positive north of the Equator and longitudes are expressed as negative west of Greenwich and east of 180° longitude.

7.1.3 Outputs from Subroutine

All outputs from the subroutine are passed through the "call argument list" and include an integer UTM zone number from 1 to 60 corresponding directly to successive 6° intervals of longitude moving eastward from 180° longitude. The UTM parameters for "northing" and for "easting," in meters, corresponding to the 500,000 meters values assigned to the Central Meridian of each zone, are returned to the calling program. An error condition indication is returned to the calling program where a value of 0 denotes "no error" and values of 1 or 2 represent errors in the range of latitude or longitude; 3 indicates an error in units.

7.1.4 Other Subroutines Used

A BLOCK DATA Subroutine is used to initialize the variables in the FORTRAN labeled COMMON "CORD," which are in FORTRAN DOUBLE PRECISION, and are a table of coefficients used in the equations to convert from coordinates expressed as latitude and longitude to UTM coordinates. It contains the FORTRAN statements: EQUIVALENCE, DATA, DOUBLE PRECISION, and COMMON.

7.2 GTGR Subroutine

7.2.1 Subroutine Description

This grid to grid conversion routine, obtained from EPA, is used when an Air Quality Control Region (AQCR) straddles a UTM zone boundary. It is necessary, in order to construct a grid made up of contiguous squares of unequal size, for a common origin to be established for the entire AQCR; that is, to establish a lower left-hand corner for the entire grid, then to relate all grid squares for the AQCR to this common origin. The mathematical formulae to convert coordinates from one UTM zone to another are those contained in the Department of the Army Technical Manual TM-5-241-8, entitled "Universal Transverse Mercator Grid" (July 1958), Chapter 5, Section 31. Tables used in the GTGR subroutine are from the Department of the Army Technical Manual TM 5-241-2. Calculations are carried out in FORTRAN DOUBLE PRECISION arithmetic and the tables for making the conversion are in a FORTRAN DEFINE FILE statement and reside on disk; only a portion of the tables are read in to central core, depending on where the point to be converted is geographically located. The subroutine permits the grid to grid conversion from east to west, or from west to east; that is, one can express the coordinates in the eastern zone as points relative to the western zone, or conversely, can express the points in the western zone as coordinates relative to the eastern zone. The CAASE system will permit either UTM zone to be declared the "primary zone" but the user is cautioned that when selecting the eastern zone as the primary zone it is possible to generate negative east-west UTM coordinates which, at this time, are unacceptable to the Implementation Planning Program (IPP). For the CAASE applications thus far, the western zone has been declared the "primary" zone with one exception. However, because a distortion error is introduced when converting from one zone to another, and is directly proportional to the distance the point is located outside of the primary zone, the user should be aware that if most of an AQCR lies in the eastern zone, but if a small portion of it extends into the western zone, less distortion will be introduced by making the eastern zone the "primary" zone. The introduction of negative easting coordinates must still be avoided.

7.2.2 Inputs to Subroutine

All inputs to subroutine GTGR are passed through the "call argument list," or read from a disk file. Inputs through the "call argument list" are the UTM "northing" coordinate, the UTM "easting" coordinate, and a variable indicating whether to convert east-to-west or west-to-east. The input UTM coordinates are modified and therefore are changed from their input values.

7.2.3 Outputs from Subroutine

All outputs from subroutine GTGR are passed to the calling program through the "call argument list" and are modified input values for the "easting" and "northing" UTM coordinates, and represent their position relative to the new (primary) zone. An error flag is set if the point to be converted lies outside the range of the tables.

7.2.4 Other Subroutines Used

No non-systems routines are used.

7.3 POPMAP Subroutine

7.3.1 Subroutine Description

POPMAP is a population map plotting routine and is called by CAASE2 to draw a map depicting centers of population and their relative population. The routine "opens" (starts) a plotter picture of the specified size, draws X and Y axes, places tick-marks along these axes, and labels the map, in addition to plotting the population data. Using scaling factors passed to the subroutine through a FORTRAN COMMON statement, a map of any practical scale can be produced. For the CAASE applications thus far, a scale of 1:250,000 has been used. For demonstrational purposes, other scales were tested. The first POPMAP subroutine call for each county causes the axes and labeling information to be produced. For each call to the routine, a triangle (it could be any of several symbols) is plotted at the center of the enumeration district, and a circle is drawn around it with its radius proportional to the population of the enumeration district. The scale used in this application was 1 inch of radius for each 4,000 people. Subroutine CIRCLE is described in Section 7.9.

7.3.2 Inputs to Subroutine

All inputs are through the FORTRAN labeled COMMON "SCALES." The inputs include the name of the state, the name of the county, the UTM coordinates of the lower left-hand corner of the county, the scale factor for the radius of each circle, the value of the scale factor for the map, the UTM coordinates of the point to be plotted, the population to be depicted at the point, the length of the X and Y axes in inches, the FORTRAN I/O unit number for the printer, the number of X and Y tick-marks wanted on the axes, and the incremental distance in inches between tick-marks. Also, an indicator is passed denoting whether it is the first call to the routine for that county; that is, must the map axes and labels be drawn. An input variable also determines whether the standard sized picture (a Y axis of 10.5 inches and an X axis of 14.0 inches) can be used. The "default" paper size on the CALCOMP plotter used in this application was 11 inches wide. Therefore, if the standard picture did not provide sufficient space there were two options: (1) that a 10.5 inch Y axis was sufficient, but that the X axis length must be increased (which did not require operator action), and (2) that the operator needed to change to the 30-inch wide paper on the plotter which made a Y axis up to 29.5 inches possible and in which case an operator message had to be issued by the POPMAP routine. In using the CAASE system and a scale of 1:250,000, most counties could be plotted with a 10.5-inch south-to-north and a 14-inch west-to-east plotter picture. Mixing the requirements for 30-inch and 11-inch wide plotter paper on the same computer run is not recommended.

7.3.3 Outputs from Subroutine

POPMAP outputs a map, drawn to scale, with axes and labeling and with a triangle representing each enumeration district center and a circle with radius proportional to its population. Error and diagnostic messages are output if necessary. As explained above, an operator message is issued when non-standard width plotter paper is needed.

7.3.4 Other Subroutines Used

Subroutines used include systems plotter routines which, although performing standard line-drawing plotter functions, may have modifications and aliases which are unique to the system that CAASE was developed on. The Triangle Universities Computer Center (TUCC), located in the Research Triangle Park, North Carolina, is the computer complex used in the development of CAASE. Plotter routines, their names, the functions they perform, and their "call argument list" requirements are briefly described as follows:

a. PICSIZ -- PICSIZ is used to open a picture on the plotter and has "call list arguments" to specify the dimensions of the picture in inches along the X axis and the Y axis, respectively. A call to the PICSIZ subroutine with the arguments (0.0, 0.0) is necessary to close the plotter file at the end of each computer run.

b. PENMSG -- The PENMSG subroutine is used to generate, on the plotter file, a computer console message to the operator at the plotter terminal. Its use in this system has been to inform the operator to place 30-inch wide paper on the plotter.

c. ORIGIN -- The ORIGIN routine is used to redefine the origin in plotter space, and is commonly used when moving the origin from the lower left-hand corner of the "picture" to an internal point to draw axes and tic-marks, etc. ORIGIN can either be progressive, i.e. cumulative, or the new origin can be relative to the corner of the total picture, which has been the application used in the CAASE system.

d. PLOT -- The PLOT program moves the plotter pen from one location within the plotter picture to another location and does it in one of the following ways: with the pen up, or with the pen down. The "call list arguments" of PLOT are an X coordinate or an array of X coordinates, followed by a Y coordinate or an array of Y coordinates, followed by an indicator to either move to the location with the pen up (if the third argument has the value 1), or denotes the size of the arrays if the third argument is greater than 1. The coordinates are expressed as floating point numbers, and represent inches in plotter space. For example, if the pen was at the origin, i.e the picture had just been opened, and the pen was to be moved to the location 4.0 in the X direction and 5.0 in the Y direction in an up position, the subroutine call would be "CALL PLOT (4.0, 5.0, 1)." However, if a line from the origin to 4.0 in X and 5.0 in Y was desired, arrays for X and Y are necessary, where X(1) = 0.0, X(2) = 4.0, Y(1) = 0.0, Y(2) = 5.0, N = 2, the call then is "CALL PLOT (X,Y,N)." Arrays of any reasonable size are possible, the only limitations being available core storage and the required plotting time.

e. SYMBOL -- This routine draws letters or other symbolic characters on the plotting paper. Any character available on an IBM 029 keypunch can be plotted; additionally, many special characters are available (for example, the Greek alphabet). Any character string can be plotted, provided it ends with an "underscore" symbol which is found on the upper case "W" on an IBM 029 keypunch, and also provided the character string is enclosed in quotes.

f. WHERE -- This routine is used to find the current location of the plotter pen, its "call list arguments" return to the calling program the present location of the pen in X and Y coordinates in plotter space inches. It has been used in the CAASE application to insert variable information in labeling a plotter chart after a string of standard characters has been drawn.

g. NUMBER -- This routine's "call list arguments" include an X coordinate, a Y coordinate, a character height expressed in inches, the name of a variable containing a floating point number, the angular displacement in degrees from the X axis, and the number of significant digits desired to the right of the decimal point. It is used to convert a floating point number to EBCDIC characters and to then draw it on the plotter — it uses "SYMBOL" after the conversion.

h. MARK -- This routine is used to plot a special character or symbol with its center at the current pen location. Its "call list arguments" include the symbol number (from a table), and the desired height of the symbol in inches. Its use in CAASE has been to draw a triangle at the center of each enumeration district, and optionally, to draw an "X" at the center of each grid square.

i. CIRCLE -- This routine was obtained from the North Carolina State University Computer Center, and is described in Section 7.9 of this manual.

7.4 POPBOX Subroutine

7.4.1 Subroutine Description

This grid drawing subroutine is called by the CAASE3 program and is used to create the plotter file for drawing a map, to scale, for the entire AQCR, once the grid has been selected off-line using outputs from the CAASE2 program. Communication with the subroutine is through the FORTRAN labeled COMMON "BOXES." The program causes a message to be issued to the operator to replace the standard 11-inch wide plotter paper with 30-inch wide paper. POPBOX is given the coordinates of the lower left-hand corner of each grid square, and its side length and it calculates the other three corners. It then causes a line to be drawn through the five points (the lower left-hand corner being both the starting and ending point). Optionally, an "X" can be drawn at the center of the grid square to aid in error checking. The axes and reference tick-marks are drawn and labeled. A map can be drawn to any scale, the only limitation being the physical size of the available plotter space. In the CAASE applications, thus far, the scale 1:250,000 has been used but, for demonstration purposes, a subset of the grid of an AQCR (ST. LOUIS) was drawn on a scale of 1:24,000. The scale factor is an input variable to the calling routine.

7.4.2 Inputs to Subroutine

All inputs are passed through the FORTRAN labeled COMMON "BOXES," and include the UTM coordinates of the lower left-hand corner of the AQCR, the name of the AQCR, the side length of each grid square, the length of the X and Y axes, the number of tick-marks on each axis (the tick-mark increment spacing has been set for 5 km and is developed by using the scale of the map to calculate the distances in plotter space), the total number of grid squares in the AQCR, and an indicator selecting the option to draw an "X" at the center of each grid square if desired.

7.4.3 Outputs from Subroutine

Outputs from the subroutine include a labeled map, drawn to scale, outlining all grid squares within the Air Quality Control Region being processed, diagnostic messages, and operator messages.

7.4.4 Other Subroutines Used

The plotter systems subroutines PICSIZ, PENMSG, ORIGIN, PLOT, SYMBOL, NUMBER, and WHERE are used, and are briefly described in Section 7.3.4 above.

7.5 READ1 Subroutine

7.5.1 Subroutine Description

This routine reads the "fuel" totals tape for the county being processed. All communication with the routine is through FORTRAN labeled COMMON. A "fuel's total" record from an edited NEDS Area Source file is read for the state, county, and AQCR of interest. The FORTRAN labeled COMMON "WHICH" is used for identification variables, the labeled COMMON "FUELS" is used to pass to the routine the variables read from the "fuels record," and the labeled COMMON "IOUNIT" is used to pass to the routine the I/O unit number assignments. This subroutine is called by the CAASE5 program.

7.5.2 Inputs to Subroutine

Although three FORTRAN labeled COMMON statements are provided, not all of the variables in these labeled COMMON's are used by READ1. The tape I/O unit number, state, county, and AQCR numbers are used. From the "fuels" tape this routine reads all of the variables appearing on the Area Source Form EPA (DUR) 219 3/72. These variables include identification information and "fuels" totals for all of the source categories currently defined.

7.5.3 Outputs from Subroutine

Outputs from this routine are passed through FORTRAN labeled COMMON and include the "fuels total record," an error indication if an "END OF FILE" condition is encountered on the tape without finding the county of interest, and an error message on the printer if the county is not found.

7.5.4 Other Subroutines Used

No non-systems routines are used.

7.6 OUTPT1 Subroutine

7.6.1 Subroutine Description

This routine, called by the CAASE5 program, formats and prints a tabular listing of the apportioned ("SMEARED") county fuel totals for all source categories on Form No. EPA (DUR) 219 3/72. All communication with the calling routine is through FORTRAN labeled COMMON statements. Five tables are produced, and apportioned fuels for up to 45 grid squares are printed on each output page. A binary tape record is written for each grid square.

7.6.2 Inputs to Subroutine

All inputs are through FORTRAN labeled COMMON statements and include the apportioned fuel totals, grid square identifications, labeling information, and I/O unit assignment numbers.

7.6.3 Outputs from Subroutine

Apportioned fuel totals, with identification and labeling information, are printed in tabular form. Five tables are produced and data for up to 45 grid squares are printed on each page. Table 1 contains identification information, apportioned fuels, and the first of six source categories, Table 2 contains abbreviated identification information and apportioned fuels for source categories 7-20, Table 3 contains abbreviated identification information and apportioned fuels for source categories 21-32. Table 4 contains abbreviated identification information and apportioned fuels for source categories 33-45, Table 5 contains abbreviated identification information and apportioned fuels for source categories 46-54. A binary tape record is written for each grid square-source category combination and includes the identification data.

7.6.4 Other Subroutines Used

No non-systems routines are used.

7.7 OUTPT2 Subroutine

7.7.1 Subroutine Description

This routine, called by the CAASE5 program, formats and prints the apportioned emissions for each source category on Form No. EPA (DUR) 219 3/72. It is called by CAASE5 five times during the processing of each county and outputs the apportioned ("SMEARED") emissions for one of the five pollutants each time it is called. The only communication with the routine that is not passed through FORTRAN labeled COMMON is a variable indicating which of the five pollutants the emissions array contains. This variable is also used to control the labeling of the tables. With the exception of formatting and labeling, OUTPT2 is very similar to OUTPT1. The routine is called by the CAASE5 program as each pollutant's emissions are calculated and "SMEARED;" this technique is used so that a larger storage array is not required, i.e. one containing all five pollutants.

7.7.2 Inputs to Subroutine

With but one exception, inputs are through FORTRAN labeled COMMON statements which provide I/O unit assignment numbers, identification information, and an array containing emissions for each source category-grid square combination. A pointer is passed through the "call argument list" to indicate which of the five pollutants the emissions array contains.

7.7.3 Outputs from Subroutine

Tabular listings of emissions, by source category-grid square combinations, are output from this routine. Up to 45 grid squares are printed on each page and, in order to deal with all source categories on Form No. EPA (DUR) 219 3/72, five tables are produced each time the routine is called. The table numbers and the source categories contained therein are the same as those described in Section 7.6.3 (OUTPT1 outputs) but the table entries are apportioned emissions instead of apportioned fuels.

7.7.4 Other Subroutines Used

No non-systems routines are used.

7.8 OUTPT3 Subroutine

7.8.1 Subroutine Description

This routine, called by the CAASE5 program, converts the total emissions apportioned to each grid square, from all source categories, from tons/year to tons/day for each of the five pollutants being processed. The routine outputs a printer line and a punched card in the Implementation Planning Program (IPP) format which was expanded to include additional data as described in Section 7.8.3 below.

7.8.2 Inputs to Subroutine

All communication with the subroutine is through FORTRAN labeled COMMON statements which contain location and labeling information, I/O unit assignment numbers, total sulfur dioxide, suspended particles, oxides of nitrogen, hydrocarbons, and carbon monoxide emissions for each grid square.

7.8.3 Outputs from Subroutine

A card is punched for each grid square in the expanded IPP format for area sources, the card image is printed on the line printer, and the data elements are written on binary tape as a separate record for each grid square.

7.8.4 Other Subroutines Used

No non-systems routines are used.

7.9 CIRCLE Subroutine

7.9.1 Subroutine Description

This routine is used for drawing circles with the plotter and was obtained from the North Carolina State University Computer Center; the exact origin of the routine is unknown. All communications with the routine are through the "call argument list." The routine has been modified to prevent the pen from leaving the plotter picture when working near the edge. CIRCLE is called by the POPMAP routine and is used to draw a circle proportional to the population count with its center at the center of an enumeradistrict. It is possible for the center of an enumeration district, represented by the coordinates from the edited MED-X census tapes, to be within the plotter picture and yet have a circle developed which would leave the picture, i.e., part of the arc along the circumference of the circle would be outside the picture. To keep this from happening, because it generates error messages from the computer's "operating system," the routine has been modified to test for the condition and the arc of the circle is truncated at the edge of the picture. This procedure still provides the user a graphical representation of the relative population because at least 180° of the arc depicting the radius of the circle would be drawn.

7.9.2 Inputs to Subroutine

All arguments in the call list are input variables. They include the X and Y coordinates of the center of the circle to be drawn, the beginning angular displacement from the positive X axis, the final displacement angle from the X axis, the beginning radius, the ending radius, the maximum plotter distance on the X axis, the maximum plotter distance on the Y axis, and a variable used for controlling the drawing of either solid lines or dashed lines. For the CAASE application, the beginning and ending radius were equal, and the beginning and ending angular displacements from the X axis were 0° and 360°, respectively.

7.9.3 Outputs from Subroutine

The subroutine writes plotter records to draw a circle.

7.9.4 Other Subroutines Used

The subroutine PLOT is used; it is described in Section 7.3.4 of this manual.

8.0 OFF-LINE GRIDDING PROCEDURE

8.1 Objective

The objective of the off-line gridding is to provide a logically determined set of grid squares to which area source emissions can be allocated on the basis of characteristics of the grid square or on the basis of subjectively, or objectively determined weighting factors. Pertinent grid square characteristics are: contained population (or its inverse), area side length, contained housing units, and housing per unit area (or its inverse). These characteristics and the introductory discussion in Section 1.0, above, indicate the dominance of population as a basis for the distribution of area source emissions.

8.2 Required Data

The gridding procedure requires, as a primary input, the plotted charts of population centers graphically showing the location and population of each enumeration district in each county of the subject AQCR. These charts are produced as output from the CAASE2 program, and are scaled to match an appropriate base map which presents topographic features, terrain characteristics, and political boundaries. The U.S. Geological Survey, 1:250,000 scale, maps have been very satisfactory as base maps for the gridding.

8.3 Procedure

While several approaches can be taken in preparing a grid for a multi-county AQCR, the following sequence has proved to be satisfactory. Alternative methods or explanator information is given as appropriate.

a. Select appropriate Geological Survey 1:250,000 scale maps to cover all counties of the AQCR. Outline each county using a felt-tipped pen of contrasting color (blue has been satisfactory). On the edges of each map where they will adjoin other map sections, extend the Universal Transverse Mercator coordinate tick-marks[*] into the map area (to preserve their location when the border is trimmed or unfolded).

b. Orient, align, and join the maps required on a working surface of suitable size.[**] Position maps for convenient use of a drafting machine or continuously parallel ruler. When orientation has been established with regard to the UTM coordinate system, secure the maps against further movement.

c. Using the UTM grid system, draw and label gridlines on each separate map. One horizontal (east-west) and one vertical (north-south) gridline on each map should be sufficient. These gridlines are used to orient the county plots of population centers, and to serve as guides for properly joining adjacent maps. Accordingly, the same UTM coordinate gridline should extend from one map to another. Where an AQCR includes more than one UTM zone, the practice has been established within the CAASE programs of relating all coordinates to the westernmost zone. Thus, the UTM grid system of the western portion of the AQCR is extrapolated with straight lines over the eastern portion of the AQCR; UTM tick-marks on maps of the eastern portion of the AQCR are ignored. An exception to this practice occurs if most of the area of the AQCR lies in the eastern UTM zone and a significantly smaller portion of the AQCR area is in the western UTM zone.

d. Overlay the Geological Survey maps with tracing paper on which the grid square system will be drawn. Fasten down the tracing paper in a manner which will allow county population charts to be

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[*] Indicated by blue tick-marks at 10,000-meter intervals on the four edges of each U.S. Geological Survey 1:250,000 scale map.

[**] A light-table, preferably with an illuminated area of approximately 3 x 3 feet, is considered essential as a working surface.

inserted and aligned between the maps and the tracing paper. Trace the UTM grid lines constructed under c, above, onto the tracing paper as guides to proper register as work continues.

e. Using the UTM grid, draw lightly a system of 10 km x 10 km coordinates over the entire AQCR. These will be used as guides to the construction of the detailed grid.

f. Arbitrarily select an initial county and trace its border onto the tracing paper (blue pencil). Insert, orient, and temporarily affix the appropriate county population chart between the map and the tracing paper.

g. Examine the relationship between the 10 km square grid drawn in e, above, and the county boundaries and the population centers. Visualize the 10 km grid displaced 5 km north, 5 km east, or both. Select the actual or visualized grid that will (1) most closely approximate the county boundary and (2) permit the largest number of rural population centers to be located near the center of a 10 km x 10 km grid square. If a displaced grid appears most appropriate for the county, construct it, again lightly in pencil, but retain the original 10 km x 10 km grid.

h. Proceed to draw grid squares, using the 5 km, or 10 km square grid and the 5 km ticks plotted on the margins of the population chart as guides. Grid squares with sides less than 5 km long are constructed by direct measurement from an existing gridline. On the 1:250,000 scale map 4 mm equals 1 km.

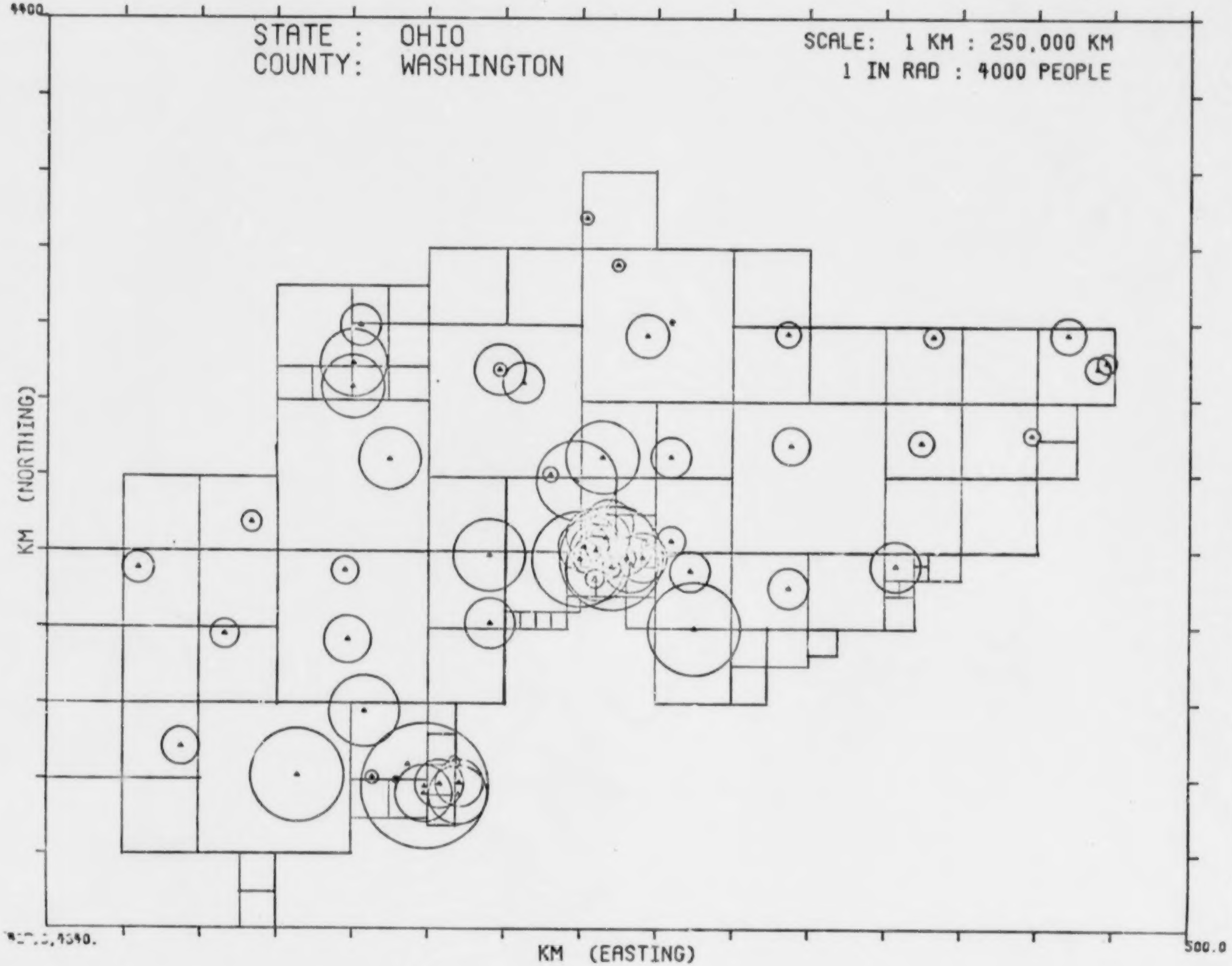
Considerable judgement must be exercised in selecting the size grid squares to be used. Topography, urbanization, forestation, transportation systems and similar features depicted on the Geological Survey maps all influence the determination of the grid square system. Some isolated population centers can readily be "framed" by squares with 10, 15, 20, 25, or even 30 km sides, without including other centers in the square. Whenever possible, these large grid squares should be used to keep the number of squares designated as small as possible. This saves both clerical time and computer requirements in later steps in the CAASE system. It is not essential that only one population center be enclosed in a grid square. Two or more population centers can fall into one grid square, provided that the map features (or more direct knowledge of the area being gridded) suggest that population distribution throughout the grid square is relatively uniform.

In gridding urban areas containing many enumeration districts, small size grid squares are used to provide a resolution compatible with the data points available. Small size squares are also used where necessary to provide a close approximation of the county boundary. However, even when the smallest practicable grid square, i.e. 1 km by 1 km, is used, occasional inclusion of population centers from the adjacent county occur, as do exclusion of population centers from the county being gridded. This is not considered serious since only small fractions of a percent of the total county population are involved.

Other occurrences of population centers falling outside the county boundaries occur as a result of errors in the location coordinates assigned to the center. Although these misplaced centers are immediately apparent when the population center chart is placed under the overlay on which the county borders have been traced, determination of the source of error usually is not feasible. If the misplaced center is not far from the county border, and is not superimposed on a population center(s) of the adjacent county the grid system being constructed possibly may be expanded to include the misplaced center. In at least one instance, all centers within a county were obviously displaced — those near the county borders by greater distances than those near the center of the county area. This situation suggested an error in a factor related to distance from the county center and a proportional correction factor was determined and applied to all coordinates. Ad hoc decisions must be made for each location error situation occurring in the plotted population charts since the position coordinates cannot be readily traced to primary source data.

i. When the grid square system for one county has been completed, a contiguous county population chart is selected and the process is repeated. No particular pattern of county selection seems preferable. Gridding of an AQCR can be done with equal facility starting with a central county, or an eastern, western, southern, or northern border county.

Figure 23 is an example of a completed county grid.


4400
STATE : OHIO
COUNTY: WASHINGTON
SCALE: 1 KM : 250,000 KM
1 IN RAD : 4000 PEOPLE
KM (NORTHING)
4340.
KM (EASTING)
500.0

9.0 OBJECTIVE APPORTIONING FACTORS AND SUBJECTIVE OVERRIDING WEIGHTING FACTORS

A basic concept in the development of the CAASE procedures was to use objective techniques, where possible, to select a grid and to apportion the area source emissions from county totals for each source category into each grid square. It was recognized that many of the source categories were amenable to apportioning as functions of the distribution of population and housing within counties. Ideally, objective methods could be used throughout the processing of area source emissions using computer processable data sources already available in computer compatible data bases. It was obvious that there were certain categories of usable data available for some counties which were not always available for other counties; further, that much of these data existed only in source document or tabular form, e.g. land use maps, traffic counts, airport operations activity, etc. A great deal of effort would be necessary to assemble these data and to incorporate them into a computer processable data base for objective apportioning. Such an effort, practical or not, was beyond the scope of the project undertaken. It appeared, however, that area source emissions for most categories were amenable to distribution by objective techniques to the grid squares of a county.

For convenience, the several fields of "fuel" data on the Area Source Input Form EPA (DUR) 219 3/72 have been sequentially numbered for category number, major classification, e.g. residential fuel, industrial fuel, etc., and minor classification, e.g. anthracite coal, bituminous coal, distillate oil, etc. Table 12 relates the category number to its major and minor classifications. Although the majority of emission source categories can be apportioned using objective techniques, provisions are made in the CAASE4 program to override any or all source categories for each grid square where available information indicates that the objective apportioning factor will not yield valid results. In order to facilitate the use of any available data for apportioning, the apportioning factor program (CAASE4) logic has been written to optionally input subjectively determined apportioning factors for any area source emissions category on EPA form number 219 (Durham 3/72) for any area source grid

AND THEIR OBJECTIVE APPORTIONING FACTOR

CATEGORY NUMBER	MAJOR CLASSIFICATION	MINOR CLASSIFICATION	OBJECTIVE APPORTIONING FACTOR*
1	RESIDENTIAL FUEL	ANTH. COAL	HOUSING UNITS
2	RESIDENTIAL FUEL	BITUM. COAL	HOUSING UNITS
3	RESIDENTIAL FUEL	DIST. OIL	HOUSING UNITS
4	RESIDENTIAL FUEL	RESID. OIL	HOUSING UNITS
5	RESIDENTIAL FUEL	NAT. GAS	HOUSING UNITS
6	RESIDENTIAL FUEL	WOOD	HOUSING UNITS
7	COMM'L & INSTITL FUEL	ANTH. COAL	POPULATION
8	COMM'L & INSTITL FUEL	BITUM. COAL	POPULATION
9	COMM'L & INSTITL FUEL	DIST. OIL	POPULATION
10	COMM'L & INSTITL FUEL	RESID. OIL	POPULATION
11	COMM'L & INSTITL FUEL	NAT. GAS	POPULATION
12	COMM'L & INSTITL FUEL	WOOD	POPULATION
13	INDUSTRIAL FUEL	ANTH. COAL	POPULATION
14	INDUSTRIAL FUEL	BITUM. COAL	POPULATION
15	INDUSTRIAL FUEL	COKE	POPULATION
16	INDUSTRIAL FUEL	DIST. OIL	POPULATION
17	INDUSTRIAL FUEL	RESID. OIL	POPULATION
18	INDUSTRIAL FUEL	NAT. GAS	POPULATION
19	INDUSTRIAL FUEL	WOOD	POPULATION
20	INDUSTRIAL FUEL	PROCESS GAS	POPULATION
21	ON-SITE INCINERATION	RESIDENTIAL	HOUSING UNITS
22	ON-SITE INCINERATION	INDUSTRIAL	POPULATION
23	ON-SITE INCINERATION	COMM'L & INSTITL	POPULATION
24	OPEN BURNING	RESIDENTIAL	HOUSING UNITS
25	OPEN BURNING	INDUSTRIAL	POPULATION
26	OPEN BURNING	COMM'L & INSTITL	POPULATION
27	GASOLINE FUEL	LIGHT VEHICLE	POPULATION
28	GASOLINE FUEL	HEAVY VEHICLE	POPULATION
29	GASOLINE FUEL	OFF HIGHWAY	1/POPULATION DENSITY
30	DIESEL FUEL	HEAVY VEHICLE	POPULATION
31	DIESEL FUEL	OFF HIGHWAY	1/POPULATION DENSITY
32	DIESEL FUEL	RAIL LOCOMOTIVE	GRID SQ. SIDE LENGTH
33	AIRCRAFT	MILITARY	AREA
34	AIRCRAFT	CIVIL	AREA
35	AIRCRAFT	COMMERCIAL	AREA
36	VESSELS	ANTH. COAL	GRID SQ. SIDE LENGTH
37	VESSELS	DIESEL OIL	GRID SQ. SIDE LENGTH
38	VESSELS	RESID. OIL	GRID SQ. SIDE LENGTH
39	VESSELS	GASOLINE	GRID SQ. SIDE LENGTH
40	EVAPORATION	SOLVENT PURCHASED	POPULATION
41	EVAPORATION	GAS MARKETED	POPULATION
42	MEASURED VEH MILES	LIMITED ACCESS RDS	1/POPULATION DENSITY
43	MEASURED VEH MILES	RURAL ROADS	1/POPULATION DENSITY
44	MEASURED VEH MILES	SUBURBAN RDS	POPULATION
45	MEASURED VEH MILES	URBAN ROADS	POPULATION
46	DIRT RDS TRAVELED	...	1/POPULATION DENSITY
47	DIRT AIRSTRIPS	...	1/POPULATION DENSITY
48	CONSTRUCT LAND AREA	...	AREA
49	ROCK HANDLG & STORAGE	...	AREA
50	FOREST FIRES	AREA-ACRES	1/POPULATION DENSITY
51	SLASH BURNING	AREA-ACRES	1/POPULATION DENSITY
52	FROST CONTROL	ORCHARD HEATERS	1/POPULATION DENSITY
53	STRUCTURE FIRES	NO. YEAR	POPULATION
54	COAL REFUSE BURNING	SIZE OF BANK	AREA

---

*Each of the above apportioning factors is multiplied by a weighting factor where some are initialized as zero for all grid squares and some are initialized as 1.0 for all grid squares. These initial weighting factors can be overridden with input data if desired.

square in the county(ies) being processed. The most extreme use of this option would be to subjectively determine the fraction of the "fuels" for each and every area source emission category, for each and every grid square being processed, and thus override all the objective terms (apportioning factors) in CAASE4; the grid used could even be one developed independently of the CAASE system — CAASE4 would simply perform some calculations for the user and provide compatible inputs to CAASE5 which would then calculate emissions and apportion them with the apportioning factors output from CAASE4.

An attempt has been made to assign an objective apportioning factor to each area source emissions category reported on EPA form number (DUR) 219 3/72. Candidate objective apportioning factors available on the Bureau of the Census MED-X* tapes, include population, housing counts, and an urban-rural classification. After the grid is established, each grid square area and side length is also available. During the attempt to assign objective apportioning factors to all source categories, the conclusion was reached that some categories, e.g. apportioning of the residential heating source categories by housing counts, were quite amenable to objective methods, while others, e.g. airport operations, were not amenable to objective apportioning and should be subjectively determined and "overridden" (provided off-line as inputs) in all cases.

Although the CAASE system permits subjective weighting factors to be assigned for any source category, from a practical standpoint they should be limited to those categories where acceptable objective data, in a computer processable form, are not available. A large number of technical personnel man-hours could be expended to "better" apportion a source category which may contribute only one or two percent of the total area source emissions and as little as one-tenth of one percent of the AQCR's total emissions (when point sources are included). To apportion emissions

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*Master Enumeration District Listing (MEDList) extended to include geographic coordinates.

from airport operations as a function directly proportional to the area of each grid square introduces a small error; however, one can quickly determine which grid squares in a county contain airports, or appear to be affected by them. On the other hand, a large amount of time could be spent in preparing overriding weighting factors for railroad operations in an urban county containing a large number of grid squares and heavy railroad activity (e.g. St. Clair County, Illinois, in the Metropolitan St. Louis AQCR) where an objective apportioning factor may yield comparable results — to apportion railroad activity as a function of grid square size may introduce insignificant and therefore acceptable percentage errors.

An important point to keep in mind when assigning overriding apportioning factors is that the factor is developed by dividing the weight assigned to the particular grid square (for a particular source category) by the sum of the weights assigned to all grid squares in the county. Therefore, whether the total refers to housing counts, area, population, or a combination of these and/or other factors will in no way modify the total emissions in the county which are to be apportioned to the individual grid squares. For each source category, the apportioning value represents each grid square's proportional share of the county total. This apportioning value is used as a numerator for the fraction of total fuels or total emissions which will be apportioned to that particular grid square for that particular source category. To sum all of the fractions for a particular source emissions category associated with each individual grid square within the county would yield unity. In order to permit the overriding of any source category-grid square combination, the apportioning number which is used is actually the product of a weighting factor and an objective apportioning factor. The weighting factors for most source categories are initially set to 1.0 (others are set to zero) by the CAASE4 program for all grid squares, which essentially removes their effect on the apportioning; that is, apportioning is totally controlled by the objective apportioning factor (value) assigned by the program (e.g. housing units), because each grid square is given the weight of 1.0. However, in the case of airport operations (source category numbers 33, 34, and 35), the weighting factors for all grid squares are initially assigned the value zero. This zero weighting factors assignment means that no emissions associated with aircraft operations will be apportioned to a grid square unless the technical personnel processing the county through the CAASE system assigns a non-zero weighting factor to a grid square(s). For aircraft operations the objective apportioning factor used is area which is then multiplied by the weighting factor (generally zero for most grid squares) to apportion the "fuels" and emissions into the grid squares where, in the user's opinion, aircraft operations contribute to pollution. Therefore, a grid square which has a large area would be apportioned more emissions than a grid square which has a smaller area (but both would have the same emissions per unit area), providing they both had equal weighting factor coefficients. The technical personnel dealing with emissions from aircraft operations could, for example, assign a 1.0 weighting factor to any grid square being affected by aircraft operations and leave the zero weighting factor in all other grid squares; the CAASE4 program would then apportion fuels and emissions strictly as a function of area; that is, a grid square of one square kilometer area would be apportioned only one twenty-fifth (1/25th) of the emissions apportioned to a five-by-five kilometer grid square representing 25 square kilometers. Or, the user could assign a value, e.g., 3.0, to the grid squares nearest an airport, 2.0 to the adjacent grid squares, and 1.0 to the furthermost grid squares being affected by aircraft operations, and leave zeroes in the remaining grid squares. This would cause both the area of the grid squares and their proximity to the airport (and aircraft operations areas) to be determining factors as to where these categories of source emissions should be apportioned within the county. It is possible, of course, to change the initialization value (in the CAASE4 program deck) for source categories 33, 34, and 35, and to simply assign a "default" weighting factor of 1.0. This would have the effect of apportioning the emissions and fuels from aircraft operations equally (emissions per unit area) throughout the county whereby grid squares with large areas would be apportioned proportionally larger portions of the emissions. It would, in effect, be analogous to an additional background concentration factor when used in a dispersion model. It is suggested that emissions from these types of activities be apportioned to grid squares which they affect where information and technical man-hours are available. The method of introducing overriding apportioning weighting factors is discussed in Section 5.3, Input Data — CAASE4.

Source emissions categories, which can be described as linear, i.e. with only length considered, are objectively apportioned as being directly proportional functions of grid square side lengths. Emissions from railroad locomotives and waterborne vessels, especially in non-urban areas, should be apportioned based on the linear variable "grid square side length" rather than the second degree variable, area. Using railroad tracks as an example (with no consideration of the relative traffic activity), if a track(s) spans a grid square then, for source emissions apportioning purposes, the basic consideration is the length of the track(s) lying within the grid square being considered. Any objectively assigned apportioning, or subjectively determined weighting, factor will be used for the later determination of the grid square's fractional contribution to the county total source emissions for railroad locomotive categories. With these goals in mind, the largest distance across a grid square is the diagonal distance through the opposite corners (e.g. northwest corner to southeast corner), and mathematically is the square root of twice the square of the side length, or simply $d = \sqrt{x^2 + y^2}$ where x and y are equal and for which the distance becomes $d = \sqrt{2x^2}$ or $\sqrt{2}\,x$. The constant $\sqrt{2}$ appears for each grid square in any summation for all non-zero apportioned grid squares and can therefore be dropped when weighing each grid square's contribution to the county total. If railroads are to be assigned subjectively determined (or alternative objective) overriding weighting factors when processing a county, then the following approaches are suggested: A scale of zero to ten (or any convenient scale) can be established whereby, for each grid square, the overriding subjectively determined weighting factor is a combination of the number of tracks crossing the grid square and what fraction of the maximum possible distance across the grid square each track represents. A single railroad track crossing the grid square coincident with one of the maximum possible distances could then, for example, be assigned the overriding apportioning factor of 1.0; two parallel tracks crossing there could then be assigned the value 2.0. One track crossing a grid square along a path one-half the distance of the maximum possible distance could be assigned the overriding factor 0.5 and if two tracks were being considered, then they could be assigned twice this value, i.e. 1.0.

As explained in other sections of this manual, a great deal of resolution (sophistication) can be introduced in the assignment of subjectively determined (or alternative objective) overriding weighting factors, but the CAASE system's user should weigh the anticipated benefits in resolution and accuracy versus the gross assumptions of annual averaging of total emissions, meteorological conditions, and the source category's percentage contributions to the total emissions; an unwarranted amount of technical-personnel time could be expended to obtain fractional percentages of change in the total air quality modeling outputs as functions of the apportioned area source inputs.

HIGHWAY AREA SOURCE METHODOLOGY

Mobile Diurnal Estimates - Highway Vehicles

Source Inventory

Activity Level - Vehicle Miles of Travel (VMT)

Area source highway vehicles VMT information taking into account temporal variation will be obtained primarily from existing VMT estimates by zone (E-W gateway). Apportioning these VMT estimates to the RAPS grid coordinate system will be accomplished through a process involving overlaying the RAPS grids over the traffic zones. In addition, apportionment will involve simultaneously overlaying these grid and zones on a detailed highway map of the area to avoid apportioning zonal VMT to grids with little or no highway miles. Further study of existing VMT data may reveal the need for supplemental research to better define temporal variation in VMT. If this becomes apparent, the missing information will be obtained by contract with the appropriate organization (e.g., E-W gateway, Mo. Highway Dept.). Stratification of VMT by vehicle weight class and non-diesel/diesel will be dealt with on the basis of land use. A sampling study (observation) will be necessary to accomplish this.

Operating Characteristics

There are three general influences that can affect the operating characteristics of highway vehicles. These are: the volume/capacity (v/c) ratio, the functional class of highway on which the travel occurs and the area type or location of this highway (e.g., Central business district, Center City). Vehicle operating characteristics on line sources are influenced by each of these variables. Area highway sources, by definition, exclude consideration of more that one functional class of highway since travel occurs only on local/collector streets. In addition, experience has shown that the range of v/c ratios encountered on local/collector streets is quite small. Therefore, at the outset, it appears that area type is the variable having the primary influence on area source highway vehicle operation along with a measure of travel density (VMT/square mile). Results of a study of operating characteristics for highway area sources will enable the assignment of the appropriate operating cycle to each zone on the basis of travel density and area type.

The development of the methodology for the operating characteristics study for highway area emission sources is to consider the collector and local classifications as one with minor arterials possibly being included if the development finds this to be appropriate. The parameters to be considered are posted speed limits, land use and total vehicle miles of travel in the place of v/c ratios if appropriate. VMT may be substituted for v/c as two travel lanes are more than enough capacity.

Emission Factors

Existing Data

Presently available light-duty vehicle data to be used in RAPS include the emission/operating mode matrix prepared for OMSAPC. A computer program prepared for OMSAPC by Calspan, Inc. (available 8/73) determines emission factors in grams per mile from this matrix for individual operating cycles. Other data required to formulate a "composite" vehicle emission factor will be arrived at using current methods (e.g., registration statistics from R.L. Polk and Company). Existing medium and heavy duty vehicle emission factors are limited to cycle results and emission "maps" (pollutant concentration versus engine load). Approximate modal emission factors can be obtained using these emission maps. A technique to do this has been developed by Watson (see H.C. Watson, The Influence of Vehicle Driving Patterns on the Localized Urban Emissions Source).

Source Testing

Several weaknesses exist in the modal emission data presently available which indicate the necessity of additional source tests. The most apparent is the lack of medium and heavy duty data compatible with existing light duty data. The light duty data for each new model year under the present OMSAPC Surveillance Program, is not available until nearly one year after the new model introductions. This represents an unacceptable time lag for the RAPS emission inventory. A validation technique involving the use of on-the-road sampling of vehicle emissions (similar to that done by McMichael and Rose) has been suggested by OMSAPC, Surveillance Branch. This suggestion will be further investigated although its inclusion into RAPS inventory is uncertain.

Source Inventory

Activity Level - Vehicle Warm-Up Operation (VWO)

VWO information per se is not available for the St. Louis area. A great deal of information is available, however, on the origins of vehicle trips.

Since the trip origin locates warmup operation geographically, VWO by traffic zone should be a readily available quantity. As with VMT, an apportionment of VWO from traffic zones to the RAPS grid system is required. The methodology used will be identical to the methodology described under activity level/ highway vehicle area sources.

Operating Characteristics

Very little is known about the operation of vehicles immediately following a start. Home interview information, obtainable from E-W. Gateway, will be used to improve our knowledge of warmup operation. Sufficient data are available, however, that detailed study of the operating condition may be held in abeyance until operating characteristics following warmup (by far the greatest percentage of operation) is better understood.

Emission Factors

Existing Data

"Start" data presently available include hot and cold start emissions from the 1975 federal test procedure at test conditions (75°F) and at ambient conditions (low and high temperatures). Data are available as the result of OMSAPC tests, Bureau of Mine tests and Environment Canada tests, all using the first 505 seconds of the 1975 federal test procedure. Further investigation of low temperature starts, again using the federal test, are being funded by OMSAPC during FY74.

Source Testing

Start emissions have been determined almost exclusively over the full first 505 seconds of the federal test, although they are approaching "stabilized" conditions sometime during that test. Little investigation has taken place to determine the change in emission characteristics of vehicle as their engines are "warming up." Unconfirmed reports have revealed that the major portion of start emission occurs during the first two minutes or less of operation. For the purposes of RAPS completeness, a start emission test program should be undertaken by OMSAPC. This study would not only improve our understanding of start emission factors but would also assist us in assigning these emissions geographically (source inventory).

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DRAFT

RIVER TOWBOAT AIR POLLUTION - ST. LOUIS, MISSOURI : AN ESTIMATION

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JANUARY 1974

Prepared for:
Department of Transportation
Office of the Secretary
Washington DC 20590

- PLEASE NOTE -

This draft manuscript is being distributed to selected individuals in the interest of information exchange and for technical review. Additional data are being gathered to permit the analysis of the traffic split between the Missouri and Mississippi Rivers and of the seasonal variations. The final report will incorporate these factors and will be published by mid-1974.

The contents of this report reflect the views of the authors. The contents do not necessarily reflect the official views or policy of the Department of Transportation. This report does not constitute a standard, specification or regulation.

DRAFT - DO NOT REPRODUCE

PREFACE

The St. Louis Air Pollution Study (SLAPS) is sponsored by several Federal agencies to explore the relationship between the urban complex and air quality. SLAPS is presently composed of several individual studies investigating the sources of air pollution, the transport and transformation of air pollutants, and the effects of air pollution upon receptors. The Department of Transportation recognizes the distinct advantages of cooperating with other studies. The Department thereby utilizes its resources to a greater advantage in deriving an extensive data base on transportation air pollution.

This study was funded by the Office of the Secretary via the Technology for Environmental Analysis Program (PPA-OS-422). This study has been conducted by the Environmental Measurements Branch, DOT/Transportation Systems Center.

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1.0 INTRODUCTION

1.1 OBJECTIVE

The objective of this effort is to obtain a realistic estimate of air pollutant emissions from the vessels which operate in the vicinity of St. Louis, Missouri, in support of the St. Louis Air Pollution Study. The emissions of interest include carbon monoxide (CO), oxides of nitrogen (NO_x), total hydrocarbon (THC), oxides of sulfur (SO_x) and particulates (Part). The estimate of emissions will be utilized by the participants of the St. Louis Air Pollution Study and are available to other Federal agencies, state and local governments, and interested parties.

1.2 SCOPE

This study is limited to the estimation of primary air pollutants emitted from the diesel engine exhaust of the river towboats. Emissions originating from the cargo, loading and unloading activities and maintenance operations are not included. The estimates are of sufficient accuracy to determine the relative contribution of river vessels to St. Louis air pollution and to serve as input data for the urban atmospheric dispersion model under development by the Federal Environmental Protection Agency for their Regional Air Pollution Study (RAPS).

Figure 1 is a map of the seven county area surrounding St. Louis which constitutes the area of interest to the St. Louis Air Pollution Study and illustrates the area's geographical nature.

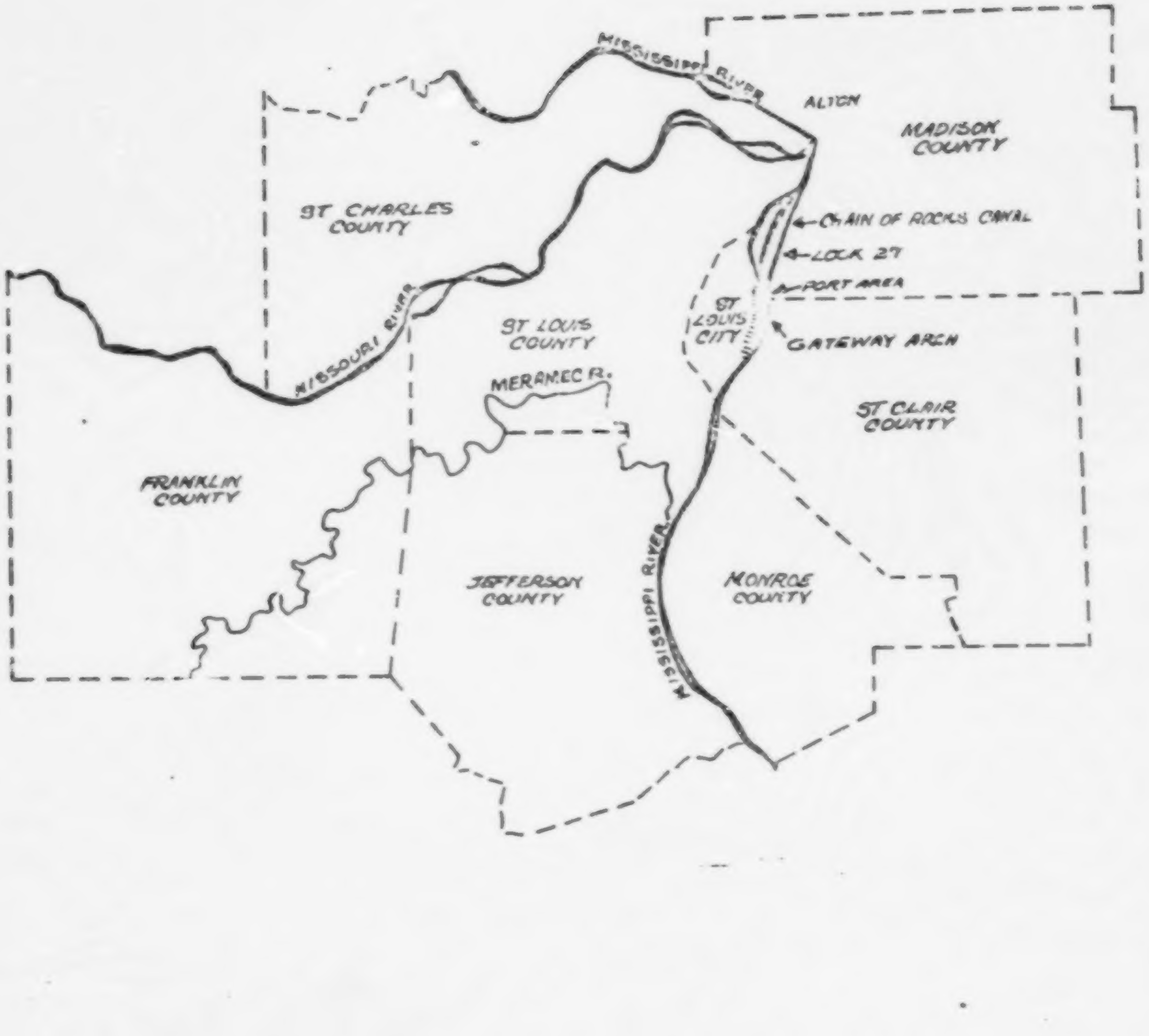
MISSISSIPPI RIVER
ALTON
MADISON COUNTY
ST CHARLES COUNTY
CHAIN OF ROCKS CANAL
LOCK 27
PORT AREA
ST LOUIS CITY
GATEWAY ARCH
MISSOURI RIVER
ST LOUIS COUNTY
MERAMEC R.
ST CLAIR COUNTY
FRANKLIN COUNTY
JEFFERSON COUNTY
MONROE COUNTY
MISSISSIPPI RIVER

Figure 1 St. Louis Air Pollution Study Area

2.0 RIVER TRAFFIC - ST. LOUIS, MISSOURI

2.1 HISTORICAL PERSPECTIVE

The American river system has provided a vital right-of-way for the transportation of commodities in this country. It contributed to the Western expansion of a century ago and today continues to promote the economic well-being of our nation.

In the early 19th century, keelboats were the primary mode of river traffic. Transportation downstream was relatively easy; but to move upstream, manual labor was needed to walk the river bank pulling the boat with ropes while others aboard pushed with poles which reached river bottom. Around the time of the Civil War, steam-powered towboats became dominant. However, freight movements were essentially with the river flow. Not until the development of propeller towboats around World War I, was there significant bi-directional freight traffic. In 1930 the diesel propeller towboat began exerting its influence on river traffic. The diese_ engine steadily replaced the steam engine as the primary propulsion for towboats.

Since the introduction of the diesel engine, waterborne freight tonnage has tripled in volume. Coupled with the development and improvement of existing waterways by the U.S. Army Corps of Engineers, the total ton mileage has increased from 9 billion in 1930 to 210 billion ton miles in 1970(1) (Numbers in parenthesis refer to References, Section 8.0).

The Mississippi River constitutes the major link for the 25,000 miles of usuable inland waterways in the United States.(2) The river is navigable from Minneapolis, MN to New Orleans, LA; St. Louis lies near the mid-point. Above St. Louis are 27 locks constructed by the U.S. Army Corps of Engineers to aid navigation. Open waters lie south of St. Louis and extend below New Orleans to the delta at the Gulf of Mexico.

2.2 ST. LOUIS-PRESENT

St. Louis is one of the busiest inland ports in the United States. It serves as a major transfer point for both upstream and downstream traffic on the Mississippi River System. Port freight volume remained rather steady in recent years. In fact its total cargo handled has increased only about 10% since 1960 while other port cities along the Mississippi have sometimes doubled or tripled in freight volume over that same period.(2)

The St. Louis port is still the third largest port on the river and the river itself in the St. Louis area handles approximately 50,000,000 tons per year in traffic, divided between terminal and thru traffic. This freight volume generates a significant amount of vessel traffic. The traffic consists primarily of towboats "pushing" barges loaded with various commodities, usually bulk in nature. Tows vary in size from one to as many as fifty or sixty barges. A typical tow is about 1100 ft. long and the combination of length and mass when acted upon by river current, wind, and dynamic effects created by proximity to flow boundaries causes considerable difficulty in steering and stopping. Tows above the St. Louis area are restricted by the

Army Corps of Engineers to 17 barges. The lock width restrictions dictate that tows be split into smaller tows with a minimum size of 2 barges in width by 6 barges in length. The Corps of Engineers provides a towboat to propel the smaller section through the lock while the original towboat propels the other section. Below St. Louis, tows are generally larger. Typical tows are usually 5 barges in length by 6 barges in width.(3)

Towboat engines range in size from around 100 hp to a maximum of 9000 hp. Towboats with engine sizes under 500 hp have proved inefficient for transporting barges over considerable distances and are generally utilized in the immediate port vicinity for preparation of larger tows. Engine sizes over 9000 hp are unlikely in the near future since engines ranging in size between 7000-9000 hp can handle as large a tow as is possible to maneuver on the Mississippi with present navigation technology.(4)

The vessel traffic in the St. Louis area is made up of transit traffic, intra-port traffic (switch boats) and the unique patterns of grid element #1078 which include the Corps of Engineers' Lock 27. Figure 2 illustrates the directional flow of traffic in the St. Louis area. Traffic estimates for each flow were needed along with an estimate of port traffic in order to arrive at accurate emissions for grid elements. The methodology developed for measuring traffic flow is presented in Section 3.0 and applied in Section 4.0.

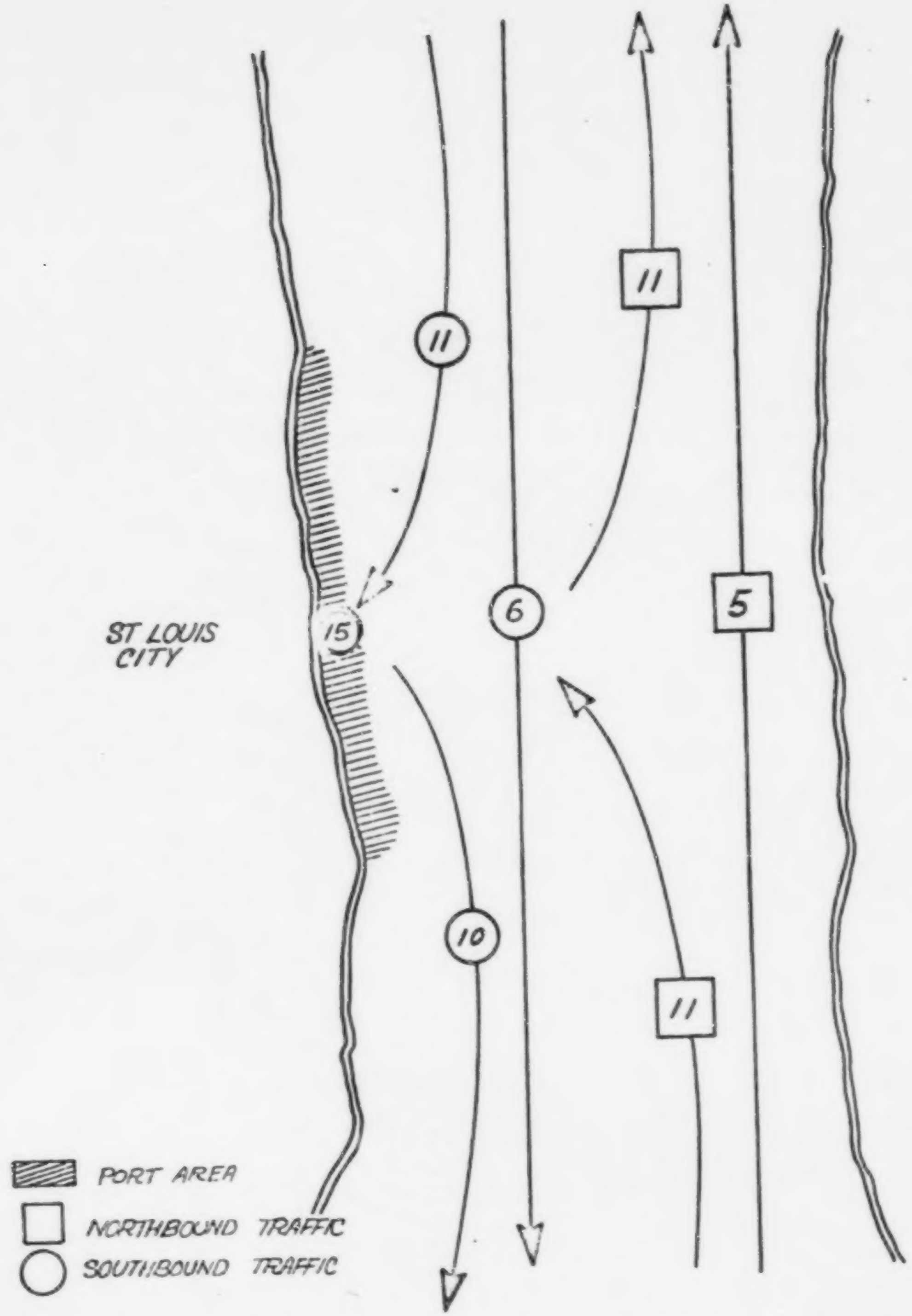
11
11
6
5
15
ST LOUIS CITY
10
11
PORT AREA
NORTHBOUND TRAFFIC
SOUTHBOUND TRAFFIC

Figure 2 Number of Transit Vessels in St. Louis Area Per Day by Direction in Terms of Origins/Destination

3.0 ASSESSMENT METHODOLOGY AND PROCEDURES

3.1 METHODOLOGY GUIDELINES

The methodology used in this study follows the guidelines presented in "Waterborne Vessel Air Pollution Study Plan for St. Louis" prepared by Raytheon Service Company for the Transportation Systems Center.(5) The referenced study plan is based upon EPA guidelines for emission source inventories.(6) Differences between the study guidelines and this study have resulted in a more comprehensive analysis since actual field data rather than estimates of vessel traffic were utilized. Other differences include:

1. Emission estimates based on average horsepower-hours rather than estimated fuel consumption,
2. Emission factors taken from direct measurements made by TSC on similar Coast Guard vessel diesel engines(7,8); from railroad locomotive diesel engines measured by Southwest Research Institute for EPA(9), and by the Southern Pacific Transportation Company.(10)

3.2 EPA GRID AREA

The Environmental Protection Agency (EPA) divided the seven county areas surrounding St. Louis into defined grid elements* specifically for their Regional Air Pollution Study which is the major program of SLAPS. These grids elements vary in size from 1 kilometer square to as much as 10 kilometers square. The size of the grid element is based upon the population and industrial density of the particular area. Emission rates for primary air pollutants will be ascertained for each element; however for

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Throughout this document the phrase grid element should be substituted for grid, grid area, or grid square. The Final Report will include this correction.

purposes of this study, only those grids which include navigable areas of the Mississippi and Missouri Rivers will be analyzed. The emissions from vessels will be combined in the future with emissions for other transportation sources, from industrial, commercial, institutional and residential sources to determine the total emissions of each pollutant for each grid element. Upon determining the total emissions for each grid element, the relative contribution of vessel emissions to St. Louis air pollution can be ascertained.

3.3 METHODOLOGY AND PROCEDURES

To achieve the basic study objective of ascertaining and documenting the amount of air pollutants emitted by towboat diesel engines, methodology was developed to inventory transit vessels traffic, switch boats activities and Lock 27 activities. The following step by step methodology was developed to fulfill the stated objective.

3.3.1 Towboats in Transit in the St. Louis Area

3.3.1.1 Engine Characteristics

Step 1 Identify the engine types by manufacturer and model which are representive of the towboat population.

Step 2 Determine the average horsepower of the towboats operating on the Mississippi River in the St. Louis area.

Step 3 Determine the horsepower utilizations factors (duty cycle) for both northbound and southbound traffic operating in the St. Louis area.

3.3.1.2 Grid Element Transit Times

Step 4 Locate the grid elements defined by the EPA on a map of the St. Louis area and identify those grid elements which contain areas of the Mississippi and Missouri Rivers used for river traffic.

Step 5 Determine the most probable trip length traveled by river traffic within each defined grid element.

Step 6 Determine the average towboat speed both north and southbound.

Step 7 Determine the average towboat transit time through each grid element by multiplying the average directional speed, determined from Step 6, by the trip distance for each grid, calculated in Step 5.

3.3.1.3 Traffic Volume

Step 8 Determine the average daily traffic volume by direction, origin, and destination of towboats in transit in the St. Louis area.

Step 9 Determine the average daily towboats traffic volume which passes into and out of each defined grid element.

3.3.1.4 Emission Factors

Step 10 Determine the emission factors for the engines identified in Step 1 for the proper horsepower utilization factor. Incorporate a frequency weighting factor for each engine to determine the average emission factor for the pollutants CO, NO_x, THC, SO_x and particulates. These emission factors will be in grams per brake horsepower hour.

3.3.1.5 Grid Emission Rates

Step 11 Determine the total horsepower hours for northbound and southbound transit traffic by computing data using the equations below.

$$P_n = t_n \times \frac{d}{S_n} \times (hp \times u_n) \ldots\ldots\ldots \text{(Eq. 1)}$$

$$P_s = t_s \times \frac{d}{S_s} \times (hp \times u_s) \ldots\ldots\ldots \text{(Eq. 2)}$$

where:

P_n, P_s = Total hp hours per day per grid for northbound (P_n) and southbound (P_s) traffic.

t_n, t_s = Average daily traffic (Steps 8,9) northbound (t_n) and southbound (t_s).

d = Grid distance computed in Step 5.

S_n, S_s = Average towboat speed (Step 6) northbound (S_n) and southbound (S_s).

hp = Average hp per towboat (Step 2).

u_n, u_s = Hp utilization factor for north (u_n) and southbound (u_s) traffic (Step 3).

Step 12 Multiply the total horsepower hours per day (P_n) obtained from (Eq. 1) by the average emission factors for northbound traffic (Step 10). Repeat the above for southbound traffic by using P_s from (Eq. 2) and the emission factors for southbound traffic.

3.3.2 Port Area Traffic

3.3.2.1 Engine Characteristics

Step 13 Identify the engine types by manufacturer and model which are representive of the port's switch boat population.

Step 14 Determine the average horsepower of the switch boats operating in the St. Louis port.

Step 15 Determine the duty cycle for the average switch boat including the horsepower utilization factor and the average total operating hours. Also determine the average horsepower spent by a towboat for switching boat operations by using the following equation.

$$AP = (hp \times u_c \times R_c) + (hp \times u_i \times R_i) \quad \text{..(Eq. 3)}$$

where:

AP = average hp utilized by towboat per hour
hp = average hp per vessel
u_c = hp utilization when not at idle
u_i = hp utilization at idle
R_c = fraction of day when not at idle
R_i = fraction of day at idle

3.3.2.2 Port Activity

Step 16 Determine switch boat traffic in the port area.

Step 17 Locate terminals and docking areas within the port area and compute terminal density for each appropriate grid.

Step 18 Determine weighting ratio per grid in proportion to the number of terminals within that grid to the total number of terminals.

3.3.2.3 Emission Factors

Step 19 Determine the emission factors for switchboats based upon Steps 13, 14, and 15 including the idle setting.

3.3.2.4 Grid Emission Rates

Step 20 Determine the total horsepower hours for switchboats operating in the port area by multiplying the number of working hours per day (Step 15) by the number of switchboats (Step 16), then multiply the product by the average hp utilization factor (Step 15).

Step 21 Compute the average horsepower hours per day for each grid using the weighted ratios for each grid (Step 18), multiplied by the total horsepower hours computed in Step 20.

Step 22 Determine the emissions from the switchboats by multiplying the total horsepower hours per grid (Step 21) by the corresponding emission factor (Step 19) and add to this the emissions at idle obtained by multiplying the time at idle (Step 15) by the corresponding emission factors (Step 19).

3.3.3 Lock 27-Grid #1078

3.3.3.1 Lock 27 Activity

Step 23 Determine the average waiting time per towboat before entering Lock 27. Determine total horsepower hours for transit traffic within grid by applying the following equations:

$$P_n = \left[(hp \times u_n \times R_c) + (hp \times u_i \times R_i)\right] \times t_n \times \frac{d}{S_n} \ldots \text{(Eq. 4)}$$

$$P_s = \left[(hp \times u_s \times R_c) + (hp \times u_i \times R_i)\right] \times t_s \times \frac{d}{S_s} \ldots \text{(Eq. 5)}$$

where:

P_n, P_s = total hp hours per grid for northbound (P_n) and southbound (P_s) traffic

hp = average hp per towboat

u_n, u_s = average hp utilized northbound (u_n) and southbound (u_s)

u_i = hp utilized when engine is at idle

R_c = fraction of day towboats are not at idle in the grid

R_i = fraction of day towboats are at idle in the grid

t_n, t_s = traffic volume northbound (t_n) and southbound (t_s)

d = grid distance in kilometers

S_n, S_s = average towboats speed northbound (S_n) and southbound (S_s).

Step 24 Determine emission factors and compute total emission rate for grid #1078 utilizing data determined in Step 23 and by applying the following equation.

$$E_i = h_i \times (t_n + t_s) \times f_i \ldots\ldots\ldots \text{(Eq. 6)}$$

where:

E_i = total emissions at idle
h_i = average number of hours towboats delayed at Lock 27
t_n, t_s = daily traffic volume northbound (t_n) and southbound (t_s) at Lock 27
f_i = emission factors at idle

.3.4 Total Emission Rates Per Grid

Step 25 Compute the total emission rates for each grid per day excluding grid #1078, by totalling the emission rates derived from Steps 12 and 22.

4.0 RIVER TRAFFIC EMISSION ESTIMATES

4.1 DATA SOURCES

Two data sources, the U.S. Army Corps of Engineers(11) and The Inland River Record(4) provided the principle data base on traffic and characteristics of the vessels operating in the St. Louis area. The Corps of Engineers operate Lock 27 located on the Chain of Rocks Canal, approximately six miles north of the Gateway Arch. All river traffic operating on the Mississippi River System above St. Louis, must pass through this lock. (See Figure 1.) Each towboat which navigates the lock has the following information recorded: vessel horsepower, arrival and departure time at the lock area, the number of barges in tow, whether the barges are empty or loaded, the total tonnage of the tow, and the vessel's origin and destination. Therefore the lock data provided an excellent source of information on river traffic characteristics. Lock data analyzed in this study are for two four day periods; August 28-31 and September 27-30, 1973.

The Inland River Record(4) documents data on approximately 3500 river vessels. Data available for each vessel include: vessel size, power plant, engine age, engine manufacturer and model type.

A simple random sample of 250 observations was taken from the Record, utilizing a series of selected random digits. Essential information about each observation was documented for analysis; e.g., total engine horsepower, engine manufacturer, engine type, etc. These data were later used in determining towboat characteristics.

4.2 TRANSIT TOWBOAT EMISSION ESTIMATES

4.2.1 Engine Characteristics

4.2.2.1 Engine Manufacturers and Model Types - Step 1

Since the data sheets obtained from the Army Corps of Engineers did not contain information on engine manufacturer and model type for each towboat, it was necessary to utilize the information obtained from The Inland River Record statistical sample. The following information was gathered concerning the manufacturers of towboat diesel engines:

- 56% manufactured by GMC
- 21% by Caterpillar
- 6% by Cummins
- 5% by Superior
- 3% by Cooper-Bessomer

The remaining 9% of the engines are manufactured by companies having less than 1% of the market.

Further analysis of the GMC data indicated that the most common type GMC engines present in the sample were:

1. GMC 567
2. GMC 645
3. GMC 71 Series

4.2.1.2 Average Horsepower Per Towboat - Step 2

From The Inland River Record sample, it was calculated that the average size of the power plant in horsepower was approximately 1200 hp. Analysis of the Corps of Engineers data produced much different results. The mean of that sample or average horsepower per vessel traveling through the lock area was 2010 hp. Table 1 is a presentation of the data from Lock #27 and the average daily horsepower per vessel for each of the 2 four-day periods.

TABLE 1. AVERAGE HORSEPOWER PER VESSEL(11)

LOCK #27

DATE 1973	DAY OF WEEK	TOTAL HP PER DAY	NUMBER OF TOWBOATS PER DAY	DAILY AVERAGE HP PER VESSEL
AUGUST				
28	Tues.	65,800	39	1687
29	Wed.	62,500	29	2155
30	Thur.	77,900	37	2105
31	Fri.	59,900	33	1815
SEPTEMBER				
27	Thur.	68,000	30	2266
28	Fri.	80,700	37	2181
29	Sat.	75,100	38	1976
30	Sun.	52,700	27	1952
TOTAL		546,200	270	

The eight day average was computed by dividing the total hp (546,200) for the eight day period by the number of observations (270) for an average of 2010 hp per vessel.

The differences in the average horsepower computed from the Corps of Engineer data and The Inland River Record is due to the inclusion of the smaller towboats (100 to 500 hp) in the Record data. These smaller towboats are normally confined to port duty and hence seldom navigate the locks.

For purposes of this study 2000 hp was used as the average horsepower per towboat. It was felt that this figure more closely approximates the characteristic horsepower of towboats in transit in the St. Louis area than the estimated horsepower from The Inland River Record sample. The actual figure of 2010 hp was rounded to 2000 hp since Corps of Engineers records horsepower in 100 hp increments.

4.2.1.3 Horsepower Utilization Factors - Step 3

Average horsepower utilization factors (duty cycles) were obtained from personnel of the U.S. Coast Guard Marine Inspection Office in St. Louis.(3) Their estimates were based on personal experience and information obtained from industry spokesmen. The estimates were an 85% utilization factor (power setting of 85% of maximum hp) for northbound traffic and a 50% utilization factor for southbound traffic. The differences is, of course, attributed to the effect of the directional flow of the river.

4.2.2 Grid Transit Times

4.2.2.1 Grid Locations - Step 4

As stated previously, grid elements as defined by the EPA were located and drawn on a map of the St. Louis area. Those grid elements which included area of the Mississippi River utilized by river traffic were identified. These grid elements are identified numerically in Column 1 of Tables 8 and 9.

4.2.2.2 Grid Transit Distance - Step 5

The maximum transit distances were derived by extending a straight line from the two most distant points on the perimeter of the grid (one north and one south) which appear to be the natural navigable traffic route. Those distances in statute miles are contained in Column 2 of Tables 8 and 9.

4.2.2.3 Average Directional Speed of Towboats in St. Louis Area - Step 6

By computing the time and distances given for typical trips from one location along the Mississippi to another, it was determined that the average speeds were 5 mph northbound and 10 mph southbound. See Table 2 for specific data.

The St. Louis to New Orleans data were weighed more heavily than the Minneapolis to St. Louis data because the latter included extensive lock time, as there are 27 locks from St. Louis to Minneapolis.

Information obtained from personnel of the U.S. Coast Guard Inspection Station, St. Louis, estimated the speeds at 5 mph northbound and 12 mph southbound.(3)

TABLE 2. TYPICAL TRANSIT TIMES FOR THE AVERAGE TOW ON THE MISSISSIPPI RIVER UNDER IDEAL CONDITIONS(12)

St. Louis to New Orleans, 1053 miles

Upstream - 8 days 19 hrs - speed 5 mph

Downstream - 4 days 9 hrs - speed 10 mph

Minneapolis to New Orleans, 1731 miles

Upstream - 11 days 22 hrs - speed 5.3 mph

Downstream - 6 days speed 9.2 mph

4.2.2.4 Average Towboat Transit Time Within Grid - Step 7

The average towboat transit time within each grid was calculated by dividing the grid distance (Step 5) by the average towboat speed both northbound (5 mph) and southbound (10 mph). A figure of ten miles per hour southbound was used instead of 12 miles per hour (Coast Guard estimate) or the 9.2 miles per hour Minneapolis to New Orleans data since the 10 mph (Table 2) figure appears more representive.

Columns 4 of Tables 8 and 9 contain the estimates of towboat transit time for northbound and southbound traffic per grid.

4.2.3 Traffic Volume

4.2.3.1 Towboat Traffic Volume - Step 8

The data obtained from Lock 27 were used to substantiate river traffic volume for the following directions and origin/destination categories:

a. Northbound traffic with a destination past St. Louis;
b. Northbound traffic with an origin of St. Louis;
c. Southbound traffic with a destination past St. Louis;
d. Southbound traffic with a destination of St. Louis.

Table 3 presents the data collected for these four categories from the Lock 27 data. Figure 2 is an illustration to assist the reader in visualizing the average daily traffic flow by origin, destination, and direction in the St. Louis area.

The two estimates which can not be extracted from the eight day survey are the northbound vessels with a destination of St. Louis and an origin below St. Louis, and southbound traffic

TABLE 3. NUMBER OF TOWBOAT TRIPS PER DAY BY DIRECTION AND ORIGIN/DESTINATION(11)

	AUGUST				SEPTEMBER					
	28	29	30	31	27	28	29	30	TOTAL	AVERAGE PER DAY
NORTHBOUND ORIGIN										
ST. LOUIS	12	12	8	11	11	8	15	9	86	11
OTHER	4	3	9	2	6	9	5	4	42	5
SOUTHBOUND DESTINATION										
ST. LOUIS	12	9	12	13	7	12	12	10	87	11
OTHER	10	6	7	6	6	6	5	4	50	6

with an origin of St. Louis and a destination below St. Louis. Attempts to find meaningful data on these two traffic flows proved extremely difficult because of the lack of records or information kept on river traffic below Lock 27, or below St. Louis. Lock 27 data did not display any identifiable diurnal variation.

The data source finally used was an U.S. Army Corps of Engineers report entitled Waterborne Commerce of the United States dated 1969.(13) The Corps of Engineers estimated that the number of towboat trips for the calendar year 1969 on the Mississippi between the mouth of the Missouri and Ohio Rivers was 17,375, with northbound and southbound traffic in equal proportion. Since the grids analyzed in this study closely approximate the river area between the Missouri and the Ohio, the data were considered acceptable.

Estimated annual tonnage volumes for this river are a increased by an annual average of 6.8% per year.(13) The increase in tonnage was considered a function of both an increase in the average tow size and the number of vessel trips per year. It was assumed that the two factors are equally weighted; therefore the annual increase in freight tonnage attributed to vessel trip increase is approximately 3.4%. Computing yearly incremented increases of 3.4% per year from 1969 to 1973, and by dividing the 1973 figures by the number of days per year, the daily estimate of traffic per day is 27 towboats northbound and 27 towboats southbound. By subtracting the number of tows by direction computed in Table 3, the estimate of towboat traffic southbound with an origin of St. Louis is 10 vessels and northbound with a destination of St. Louis is 11 vessels. (See Figure 2 in Section 2.0).

4.2.3.2 Average Daily Traffic Volume Per Grid - Step 9

Step 8 determined the average daily traffic volume by directions, origin, and destinations for towboats operating in the St. Louis area. Using these traffic volumes, it is possible to calculate the average number of towboats passing point X on the perimeter of each grid square. It was assumed that any vessel passing point X, which is in this case on the northern grid perimeter for southbound traffic and on the southern perimeter for northbound traffic, will proceed through the entire grid element. No provision was made for traffic stopping within the grid element because this study utilizes average number of vessels and not actual towboat transits. It can also be assumed that the traffic terminating within a grid would be approximately equal to the traffic originating within that grid (which would not be counted because of the methodology established); thus one would negate the other.

Another problem in allocating traffic volume to particular grids is that the St. Louis port area encompasses 17 grid elements. The point at which traffic terminates or originates along the 17 grid element and the volume of that traffic are unknown. However it was assumed that originating and terminating traffic within the port area is evenly distributed, so that the originating and terminating traffic negating each other.

Columns 3, Table 8 (Northbound) and Table 9 (Southbound) contain the estimated average daily traffic volume by direction for each grid square.

4.2.4 Emission Factors - Step 10

The emission factors for the three engines identified in Section 4.2.2.1 were used to arrive at average emission factors for towboats. These engine types were used to determine the composite emission factors since they propel the majority of the towboat fleet and their emission factor data are readily available. Figure 3 illustrates the total horsepower of the three engines for the established sample; the figures were derived by multiplying the horsepower per engine by the number of engines in the sample possessing that horsepower. GM engines were used exclusively because the GM engine represents over 75% of the total horsepower in the statistical sample taken from The Inland River Record.

Table 4 contains the data used to formulate the emission factors minus SO_x and particulates for the three GM engines at an 85% utilization rate. Table 5 gives comparable information for the engines at 50% of full capacity. The emission factors for each engine type were weighted in proportion to the percentage of its horsepower to the total fleet horsepower. Table 6 gives the final weighted emission factors for 85% and 50% power settings. These data were used in calculating the total air pollutant emissions for each grid.

Emission factors for SO_x and particulates were not available from actual measurements as were the other primary pollutants. An EPA document(13) was used which gives estimates for heavy-duty truck and locomotive diesel engines. Since towboat engines are essentially the same as truck and locomotive engines, with slight modifications, these emission factors were considered acceptable

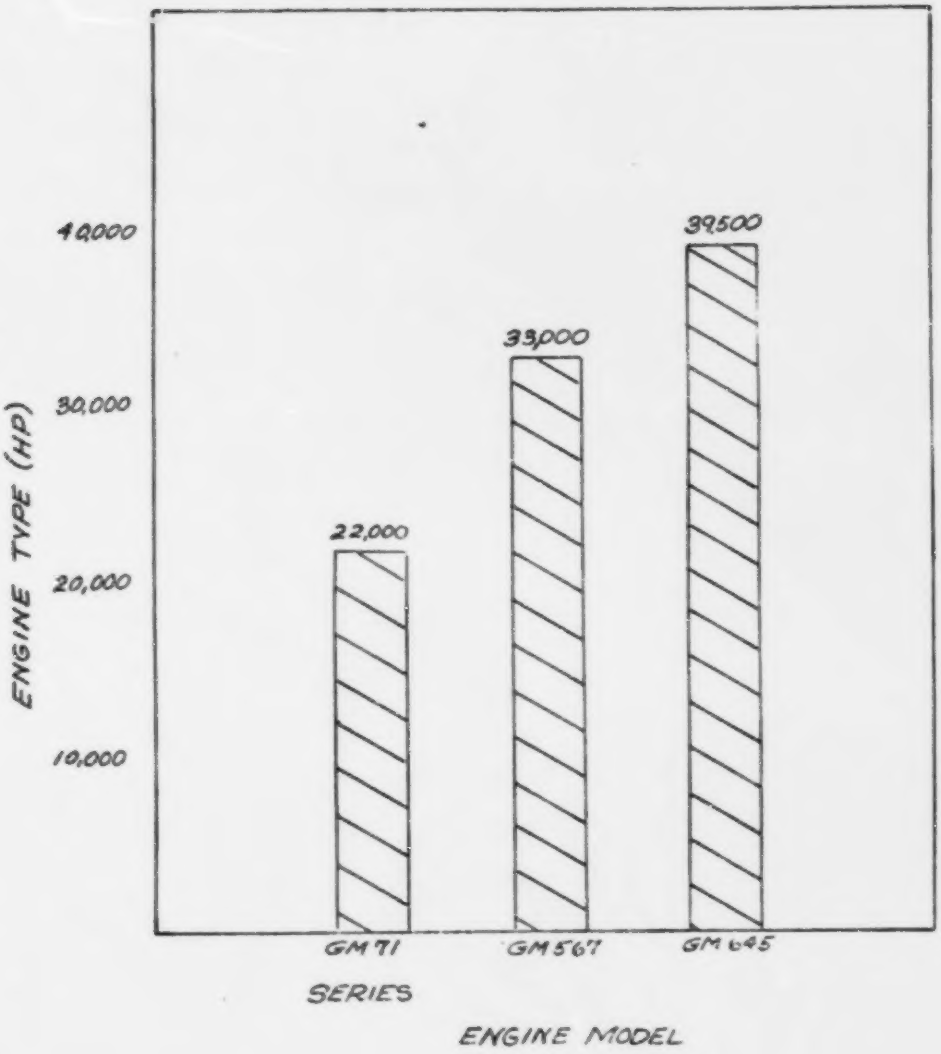

Figure 5. Horsepower Times Number of Engines in Statistical Sample

TABLE 4. EMISSION FACTORS (MINUS SO_x AND PART) FOR THE MOST PROMINENT GM ENGINES (85% UTILIZATION) (IN GRAMS PER HORSEPOWER HOUR)

ENGINE	EMISSION FACTORS		
	g/hp-hr		
	CO	NO_x	THC
GM-645 (9,10)*	2.1	11.8	.6
	2.4	13.0	.8
	2.5	8.2	.6
	3.5	7.7	.5
Avg. g/hp hr	2.6	10.1	.6
GM-567 (9)*	3.2	11.4	1.3
	3.8	11.7	1.1
	.9	8.6	3.2
	.9	8.4	3.4
Avg. g/hp hr	2.2	10.0	2.3
GM-71 Series (7)*	6.8	10.7	1.1
	8.7	12.8	5.1
	11.2	13.5	4.1
Avg. g/hp hr	8.9	12.3	3.4

*Multiple data points.

TABLE 5. EMISSION FACTORS (MINUS SO_x AND PART) FOR THE MOST PROMINENT GM ENGINES (50% UTILIZATION) (IN GRAMS PER HORSEPOWER HOUR)

ENGINE	EMISSION FACTORS		
	g/hp hr		
	CO	NO_x	THC
GM-645(9,10)*	2.0	13.0	.7
	1.0	10.0	.8
	8.2	7.6	.4
	8.3	7.3	.4
	4.9	7.5	.4
	8.6	6.8	.5
Avg. g/hp hr	5.5	8.7	.5
GM-567(9)*	1.9	8.1	4.5
	1.8	5.0	4.1
	1.3	6.1	4.1
Avg. g/hp hr	1.6	6.4	4.2
GM-71 Series(7)*	2.6	10.5	2.8
	3.0	12.1	5.7
	6.8	14.1	4.2
Avg. g/hp hr	4.2	12.2	4.2

*Multiple data points

TABLE 6. COMPOSITE EMISSION FACTORS (MINUS SO_x AND PARTICULATES)

ENGINE	% OF TOTAL HP	Emission Factors g/hp-hr			Weighted Emission Factors (g/hp-hr X %)			Composite Emission Factors g/hp-hr
AT 85% POWER SETTING								
		CO	NO_x	THC	CO	NO_x	THC	
GM71 Series	23%	8.9	12.3	3.4	2.0	2.8	0.8	CO 3.9
GM567	35%	2.2	10.0	2.3	0.8	3.5	0.8	NO_x 10.6
GM645	42%	2.6	10.1	.6	1.1	4.3	0.2	THC 1.8
AT 50% POWER SETTINGS								
GM71 Series	23%	4.2	12.2	4.2	1.0	3.0	1.0	CO 3.9
GM567	35%	1.7	6.4	4.2	0.6	2.2	1.5	NO_x 8.9
GM645	42%	5.5	8.7	0.5	2.3	3.7	0.2	THC 2.7

for this study. Factors of 1.4 grams per horsepower hour for SO_x and .6 grams for particulates were derived from the calculations present in Table 7.

4.2.5 Grid Emission Rates

4.2.5.1 Total Vessel Horsepower Hours for Northbound and Southbound Traffic - Step 11

The formulae used to compute total horsepower hours per grid element per day are given by Eqs. 1 and 2, Section 3.3.1.5 and are repeated below.

$$P_n = t_n \times \frac{d}{S_n} \times (hp \times u_n) \text{.............. (Eq. 1)}$$

$$P_s = t_s \times \frac{d}{S_s} \times (hp \times u_s) \text{.............. (Eq. 2)}$$

where:

P_n, P_s = Total hp hours per day per grid for northbound (P_n) and southbound (P_s) traffic.

t_n, t_s = Average daily traffic (Step 8, 9) northbound (t_n) and southbound (t_s).

d = Grid distance computed in Step 5 (in nm).

S_n, S_s = Average towboat speed (Step 6) northbound (S_n) and southbound.

hp = Average hp per towboat (Step 2).

u_n, u_s = Hp utilization factor for northbound (u_n) and southbound (u_s) traffic.

Below is a sample calculation for a grid element (#1234):

TABLE 7. EMISSIONS FACTORS FOR SO_x AND PARTICULATES(13)

Emissions in Grams per HP Hour*

	Diesel truck engine (GM-71 Series)	Locomotive engine (GM 567 and 645)
Part	.3 g/hp hr	.6 g/hp hr
SO_x	.7 g/hp hr	1.6 g/hp hr

Weighted Emission Factors - Particulates

Engine Types	% of Total	Emission Factors	Weighted Emission Factors
GM-71 Series	23%	.3 g/hp hr	.1
GM567 & 645	77%	.6 g/hp hr	.5
			.6g/hp hr

Weighted Emission Factors - SO_x

Engine Types	% of Total	Emission Factors	Weighted Emission Factors
GM-71 Series	23%	.7	.2
GM 567 & 645	77%	1.6	1.2
			1.4 g/hp hr

*Emissions were recorded in lbs of pollutants per thousand gallons of fuel in the reference source. Emission factors were converted to grams per hp hour in keeping with the study methodology by using the conversation factor 0.4 lbs of fuel per horsepower-hour.

$$P_n = 16 \times \frac{2.7}{5} \times (2000 \times .85)$$

$$P_n = 14,688 \text{ hp hrs}$$

$$P_s = 17 \times \frac{2.7}{10} \times (2000 \times .50)$$

$$P_s = 4590 \text{ hp hrs}$$

Column 5 of Tables 8 and 9 contain the total horsepower hours for both northbound and southbound traffic for each grid element.

4.2.5.2 Pollutants Per Grid for Northbound and Southbound Traffic - Step 12

Columns 6 through 10 of Tables 8 and 9 contain the estimated pollutants for CO, NO_x, total hydrocarbons (THC), SO_x, and particulates for northbound and southbound traffic. These figures were arrived at by multiplying the emission factors calculated in Step 10 by the total horsepower hours by direction calculated in Step 11 above.

4.3 PORT AREA TRAFFIC

All of the above calculations pertain to traffic generated by towboats which are transit on the river. Purposely omitted is the amount of traffic within the St. Louis area caused by switching boats responsible for "spotting" barges when making and breaking tows and moving barges to docks and yards.

TABLE 8. EMISSION RATES FOR NORTHBOUND TRAFFIC PER GRID PER DAY

(IN GRAMS OF POLLUTANTS)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
					EMISSION RATES (IN GRAMS)				
GRID NO.	GRID DISTANCE IN KILOMETERS	DAILY VESSELS NORTHBOUND	GRID DISTANCE/ SPEED NORTH-BOUND	HP HOURS NORTHBOUND	CO EMISSION IN GRAMS (3.9 GRAMS PER HP HR)	NO_x EMISSION IN GRAMS (10.6 GRAMS PER HP HR)	TOTAL HC IN GRAMS (1.8 GRAMS PER HP HR)	SO_x 1.4 grams/ HP HOUR	PART. .6 GRAMS HP HOUR
1234	2.7	16	.54	14,688	57,283	155,693	26,438	20,563	8,813
1233	2.9		.58	15,776	61,526	167,226	28,396	22,086	9,466
1194	1.9		.38	10,336	40,310	109,562	18,605	14,470	6,202
1195	.6		.12	3,264	12,730	34,598	5,875	4,570	1,958
1166	.7		.14	3,808	14,851	40,365	6,854	5,331	2,285
1165	1.2		.24	6,528	25,459	69,197	11,750	9,139	3,917
1151	.8		.16	4,352	16,973	46,131	7,834	6,093	2,611
1132	1.2		.24	6,528	25,459	69,197	11,750	9,139	3,917
1131	.4		.08	2,176	8,486	23,066	3,917	3,046	1,306
1080	.9		.19	5,168	20,155	54,781	9,302	7,235	3,101
1079	2.2		.44	11,968	46,675	126,861	21,542	16,755	7,181
1078	1.2		.24	5,712	22,277	60,547	10,282	7,997	3,427
1010	1.2		.24	6,528	25,459	69,197	11,750	9,139	3,917
1040	1.0		.20	5,440	21,216	57,664	9,792	7,616	3,264
1039	1.1		.22	5,984	23,338	63,430	10,771	8,378	3,590
1038	.6		.12	3,264	12,730	34,598	5,875	4,570	1,958
1074	.8		.15	4,080	15,912	43,248	7,344	5,712	2,448
1073	1.0		.20	5,440	21,216	57,664	9,792	7,616	3,264
1072	1.0		.20	5,440	21,216	57,664	9,792	7,616	3,264
1071	1.0		.20	5,440	21,216	57,664	9,792	7,616	3,264
1070	1.0		.20	5,440	21,216	57,664	9,792	7,616	3,264
1069	1.0		.20	5,440	21,216	57,664	9,792	7,616	3,264
1068	1.0		.20	5,440	21,216	57,664	9,792	7,616	3,264
1067	.8		.15	4,080	15,912	43,248	7,344	5,712	2,448

TABLE 8. EMISSION RATES FOR NORTHBOUND TRAFFIC PER GRID PER DAY (Continued)

(IN GRAMS OF POLLUTANTS)

(1) GRID NO.	(2) GRID DISTANCE IN KILOMETERS	(3) DAILY VESSELS NORTHBOUND	(4) GRID DISTANCE/ SPEED NORTH-BOUND	(5) HP HOURS NORTHBOUND	(6) CO EMISSION IN GRAMS (3.9 GRAMS PER HP HR)	(7) NO_x EMISSION IN GRAMS (10.6 GRAMS PER HP HR)	(8) TOTAL HC IN GRAMS (1.8 GRAMS PER HP HR)	(9) SO_x 1.4 grams/ HP HOUR	(10) PART. .6 GRAMS HP HOUR
1031	1.1	16	.22	5,984	23,338	63,430	10,771	8,378	3,590
1030	1.4		.27	7,344	28,642	77,846	13,219	10,282	4,406
999	.3		.05	1,360	5,304	14,416	2,448	1,904	816
998	1.6		.32	8,704	33,946	92,262	15,667	12,186	5,222
955	1.5		.29	7,888	30,763	83;613	14,198	11,043	4,733
954	.3		.05	1,360	5,304	14,416	2,448	1,904	816
925	.6		.12	3,264	12,730	34,598	5,875	4,570	1,958
924	1.4		.28	7,616	29,702	80,730	13,709	10,662	4,570
889	.4		.08	2,176	8,486	23,066	3,917	3,046	1,306
923	.6		.12	3,264	12,730	34,598	5,875	4,570	1.958
888	1.0		.20	5,440	21,216	57,664	9,792	7,616	3,264
887	1.3		.26	7,072	27,581	74,963	12,730	9,901	4,243
849	.3		.06	1,632	6,365	17,299	2,938	2,285	979
848	1.2		.24	6,528	25,459	69,197	11,750	9,139	3,917
847	1.2		.24	6,528	25,459	69,197	11,750	9,139	3,917
846	.5		.10	2,720	10,608	28,832	4,896	3,808	1,632
815	.3		.06	1,632	6,365	17,299	2,938	2,285	979
814	1.2		.24	6,528	25,459	69,197	11,750	9,139	3,917
813	2.1		.42	11,424	44,554	121,094	20,563	15,994	6,854
812	2.6		.52	14,144	55,162	149,926	25,459	19,802	8,486
811	1.3		.26	7,072	27,581	74,963	12,730	9,901	4,243
700	2.6		.52	14,144	55,162	149,926	25,459	19,802	8,486
699	3.6		.72	19,584	76,378	207,590	35,251	27,418	11,750

TABLE 9. EMISSION RATES FOR SOUTHBOUND TRAFFIC PER GRID PER DAY

(IN GRAMS OF POLLUTANTS)

(1) GRID NO.	(2) GRID DISTANCE IN KILOMETERS	(3) DAILY VESSELS SOUTHBOUND	(4) GRID DISTANCE/ SPEED SOUTH-BOUND	(5) HP HOURS SOUTHBOUND	(6) CO EMISSION IN GRAMS (3.9 GRAMS PER HP HR)	(7) NO_x EMISSION IN GRAMS (8.9 GRAMS PER HP HR)	(8) TOTAL HC IN GRAMS (2.7 GRAMS PER HP HR)	(9) SO_x 1.4 grams/ HP HOUR	(10) PART. .6 GRAMS HP HOUR
1234	2.7	17	.27	4,590	17,901	40,851	12,393	6,426	2,754
1233	2.9		.29	4,930	19,227	43,877	13,311	6,902	2,958
1094	1.9		.19	3,230	12,597	28,747	8,721	4,522	1,938
1195	.6		.06	1,020	3,978	9,078	2,754	1,428	612
1166	.7		.07	1,190	4,641	10,591	3,213	1,666	714
1165	1.2		.12	2,040	7,956	18,156	5,508	2,856	1,224
1081	.8		.08	1,360	5,304	12,104	3,672	1,904	816
1132	1.2		.12	2,040	7,956	18,156	5,508	2,856	1,224
1131	.4		.04	680	2,652	6,057	1,836	952	408
1130	.9		.10	1,700	6,630	15,130	4,590	2,380	1,020
1079	2.2		.22	3,740	14,586	33,286	10,098	5,236	2,244
1078	1.2		.12	1,785	6,962	15,887	4,820	2,499	1,071
1010	1.2		.12	2,040	7,956	18,156	5,508	2,856	1,224
1040	1.0		.10	1,700	6,630	15,130	4,590	2,380	1,020
1039	1.1		.11	1,870	7,293	16,643	5,049	2,618	1,122
1038	.6		.06	1,020	3,978	28,747	2,754	1,428	612
1074	.8		.08	1,360	5,304	12,104	3,672	1,904	816
1073	1.0		.10	1,700	6,630	15,130	4,590	2,380	1,020
1072	1.0		.10	1,700	6,630	15,130	4,590	2,380	1,020
1071	1.0		.10	1,700	6,630	15,130	4,590	2,380	1,020
1070	1.0		.10	1,700	6,630	15,130	4,590	2,380	1,020
1069	1.0		.10	1,700	6,630	15,130	4,590	2,380	1,020
1068	1.0		.10	1,700	6,630	15,130	4,590	2,380	1,020
1067	.8		.08	1,360	5,304	12,104	3,672	1,904	816
1031	1.1		.11	1,870	7,293	16,643	5,049	2,618	1,122
1030	1.4		.14	2,380	9,282	21,182	6,426	3,332	1,428
999	.3	16	.03	480	1,872	4,272	1,296	672	288

TABLE 9. EMISSION RATES FOR SOUTHBOUND TRAFFIC PER GRID PER DAY (Continued)

(IN GRAMS OF POLLUTANTS)

(1) GRID NO.	(2) GRID DISTANCE IN KILOMETERS	(3) DAILY VESSELS SOUTHBOUND	(4) GRID DISTANCE/ SPEED SOUTH-BOUND	(5) HP HOURS SOUTHBOUND	(6) CO EMISSION IN GRAMS (3.9 GRAMS. PER HP HR)	(7) NO_x EMISSION IN GRAMS (8.9 GRAMS PER HP HR)	(8) TOTAL HC IN GRAMS (2.7 GRAMS PER HP HR)	(9) SO_x 1.4 grams/ HP HOUR	(10) PART. .6 GRAMS HP HOUR
958	1.6	16	.16	2,560	9,984	22,784	6,912	3,584	1,536
955	1.5		.15	2,400	9,360	21,360	6,480	3,360	1,440
954	.3		.03	480	1,872	4,272	1,296	672	288
925	1.6		.06	960	3,744	8,544	2,592	1,344	576
924	1.4		.14	2,240	8,736	19,936	6,048	3,136	1,344
889	.4		.04	640	2,496	5,696	1,728	896	384
923	.6		.06	960	3,744	8,544	2,592	1,344	576
858	1.0		.10	1,600	6,240	14,240	4,320	2,240	960
857	1.3		.13	2,080	8,112	18,512	5,616	2,912	1,248
849	.3		.03	480	1,872	4,272	1,296	672	288
848	1.2		.12	1,920	7,488	17,088	5,184	1,288	1,152
847	1.2		.12	1,920	7,488	17,088	5,184	1,288	1,152
846	.5		.05	800	3,120	7,120	2,160	1,120	480
815	.3		.03	480	1,872	4,272	1,296	672	288
814	1.2		.12	1,920	7,488	17,088	5,184	1,288	1,152
813	2.1		.21	3,360	13,104	29,904	9,072	4,704	2,016
812	2.6		.26	4,160	16,224	37,024	11,232	5,824	2,496
811	1.3		.13	2,080	8,112	18,512	5,616	2,912	1,248
700	2.6		.26	4,160	16,224	37,024	11,232	5,824	2,496
699	3.6		.36	5,760	22,464	51,264	15,552	8,064	3,456

4.3.1 Engine Characteristics

4.3.1.1 Engine Type - Step 13

Since switching boats have smaller power plants than transit towboats, the smaller type engine, GM-71 series, was considered typical of switching boat engines. Analysis was therefore based on emission factors for this model diesel engine.

4.3.1.2 Average Switchboat Horsepower - Step 14

Switching boat engines usually range from 300 to 500 horsepower.(3) An average of 400 hp was used for this analysis.

4.3.1.3 Operating Characteristics - Step 15

Switching boats operate part of the day with their engines at idle because of the nature of their operations; therefore the following duty cycle was assumed.

- 1/2 of the operating period at idle
- 1/2 of the operating period at 50% power setting.

The duty cycle was assumed to be applicable for all switching boats in the port area. It was estimated that the duty cycle for switching boats was 8 hours for a normal working day.

The following equation repeated from Section 3.3.2.1 was used to compute an estimate for the average horsepower spent for switching boat operations.

$$AP = (hp \times u_c \times R_c) + (hp \times u_i \times R_i) \ldots\ldots \text{(Eq. 3)}$$

where:

AP = average hp utilized by towboat per hour

hp = average hp per vessel (400 hp)

u_c = hp utilization when not idle (50%)

u_i = hp utilization at idle (0%)

R_c = fraction of day when not at idle (1/2)

R_i = fraction of day at idle (1/2)

Coefficients are inserted for equation 3 below:

$$\frac{400 \text{ hp} \times .5}{2} \times \frac{400 \text{ hp} \times 0}{2} = 100 \text{ hp}$$

The coefficient for R_i is zero because theoretically an engine at idle is operating at zero brake horsepower. Therefore the average horsepower utilized by a switchboat is 100 hp per hour.

4.3.2 Port Activity

4.3.2.1 Switchboat Traffic - Step 16

Personnel at the U.S. Coast Guard Station in St. Louis estimated that there were 15 towboats or tugboats operating as switching boats within the port area.(3) Since this was the only information available, the switchboat traffic density was assumed to be 15 vessels per day.

4.3.2.2 Location of Terminals and Docks - Step 17

An Army Corps of Engineers' publication listing Mississippi River terminals, docks, mooring locations and warehouses was used to locate the terminals and docking areas within each grid element.(15) Table 10 cites those grids (Column 1) and gives the number of terminals within that grid, Column 2.

TABLE 10. ALLOCATION OF SWITCHING BOAT HP HOURS TO GRID AREAS

(1) GRID #	(2) NO. OF TERMINALS	(3) WEIGHTING FACTORS	(4) HP HOURS* PER GRID
1010	5	.08	960
1073	4	.06	720
1072	6	.08	960
1069	4	.06	720
1038	2	.03	360
1032	4	.06	720
1031	4	.06	720
1030	5	.08	960
999	4	.06	720
998	6	.09	1080
955	8	.12	1440
924	3	.04	480
849	2	.03	360
848	3	.04	480
847	4	.06	720
815	3	.04	480
Total	67	.99*	11,880**

*as % of 12,000 hp hrs
**1% due to rounding = 120 hp hours

4.3.2.3 Terminal Weighting Factors - Step 18

Table 10, Column 3 lists the weighting factors arrived at by dividing the number of terminals within each grid element by the total number of terminals, 67.

4.3.3 Emission Factors - Step 19

So far in this study all emission rates have been based on grams per horsepower hour. However when a towboat engine is idling, theoretically it is operating at zero brake horsepower. Therefore emission rates at idle were derived by using emission rates in grams per hour. The following emission rates in grams per hour were used for an engine at idle.

TABLE 11. EMISSION FACTORS AT IDLE(7,13)

400 HP Diesel Engine

CO - 1560 grams/hour

NO_x - 95 grams/hour

THC - 535 grams/hour

SO_x - 27 grams/hour

Part - 13 grams/hour

The data for NO_x, CO, and THC were calculated for a 400 hp GM-71 Series engine. These data are considered representative of the total switchboat population.

Emission factors used for switchboats at 50% of horsepower capacity were the same as those calculated in Table 6 for the GM-71 Series, and Table 7 for SO_x and particulates.

4.3.4 Grid Emission Rates

4.3.4.1 Total Horsepower Hours for Switchboats - Step 20

The number of switchboats (15) was multiplied by the number of working hours per day (8), which was in turn multiplied by the average horsepower utilized by switchboats (100 hp). The result was a total of 12,000 hp hours per day for the St. Louis port area.

4.3.4.2 Average Horsepower Hours Per Grid - Step 21

Column 4 of Table 10 contains the average hp hours for each grid computed by multiplying the total hp hours (12,000) arrived at in Step 20 by the weighting factors calculated in Step 18.

4.3.4.3 Total Emission Rates Per Grid - Step 22

Table 12 lists the emission rates for the primary pollutants caused by switchboats at idle for each grid. These data were computed by multiplying the total hours at idle (60 hrs) by the emission factors listed in Table 11. The weighting factors per grid were again applied to arrive at emission rates per grid.

Table 13 cites the emission rates for each grid at 50% hp utilization. Table 14 gives the total pollution volumes for each grid derived by adding rates from Tables 12 and 13.

4.4 LOCK 27-GRID # 1078

Grid 1078 has an unique characteristic which separates it from the rest of the grid areas in the St. Louis area, and thus requires a distinct methodology to compute horsepower hours and emissions.

Located within grid 1078 is Lock 27 which is operated by the Army Corps of Engineers. Towboats must utilize the lock in order to operate above the St. Louis area or reach St. Louis from a location above the city. Because of high traffic volume, towboats are frequently required to wait before entering the lock. Data from the 8-day Lock 27 study established a waiting time of 3 hours

TABLE 12. SWITCHBOATS EMISSIONS AT IDLE PER GRID PER DAY

IN GRAMS PER DAY

Grid#	Weighting Factors	CO % of 93,600g.	NO_x % of 5,700g.	THC % of 32,100g.	SO_x % of 3564g.	Part % of 1716g.
1010	.08	7,488	456	2,568	285	137
1073	.06	5,616	342	1,926	214	103
1072	.08	7,488	456	2,568	285	137
1069	.06	5,616	342	1,926	214	103
1038	.03	2,808	171	963	107	51
1032	.06	5,616	342	1,926	214	103
1031	.06	5,616	342	1,926	214	103
1030	.08	7,488	456	2,568	285	137
999	.06	5,616	342	1,926	214	103
998	.09	8,424	513	2,889	321	154
955	.12	11,232	684	3,852	428	206
924	.04	3,744	228	1,284	143	69
849	.03	2,808	171	963	107	51
848	.04	3,744	228	1,284	143	69
847	.06	5,616	342	1,926	214	103
815	.04	3,744	228	1,294	143	69

TABLE 13. EMISSIONS FOR SWITCHBOATS AT 50% CAPACITY PER GRID PER DAY

		EMISSIONS IN GRAMS PER DAY				
Grid#	HP HOURS	CO 4.2grams/ hp hr	NO_x 12.2grams/ hp hr	THC 4.2grams/ hp hr	SO_x 0.7 g/hp hr	Part 0.3 g/hp hr
1010	960	4,032	11,712	4,032	672	288
1073	720	3,024	8,784	3,024	504	216
1072	960	4,032	11,712	4,032	672	288
1069	720	3,024	8,784	3,024	504	216
1038	360	1,512	4,392	1,512	252	108
1032	720	3,024	8,784	3,024	504	216
1031	720	3,024	8,784	3,024	504	216
1030	960	4,032	11,712	4,032	672	288
999	720	3,024	8,784	3,024	504	216
998	1080	4,536	13,176	4,536	756	324
955	1440	6,048	17,568	6,048	1,008	432
924	480	2,016	5,856	2,016	336	144
849	360	1,512	4,392	1,512	252	108
848	480	2,016	5,856	2,016	336	144
847	720	3,024	8,784	3,024	504	216
815	480	2,016	5,856	2,016	336	144

TABLE 14. TOTAL EMISSIONS FOR SWITCHBOATS PER GRID PER DAY

EMISSIONS IN GRAMS PER DAY

Grid#	CO	NO_x	THC	SO_x	Part
1010	11,520	12,168	6,600	957	425
1073	8,640	9,126	4,950	718	319
1072	11,520	12,168	6,600	957	425
1069	8,640	9,126	4,950	718	319
1038	4,320	4,563	2,475	359	159
1032	8,640	9,126	4,950	718	319
1031	8,640	9,126	4,950	718	319
1030	11,520	12,168	6,660	957	425
999	8,640	9,126	4,950	718	319
998	12,960	13,689	7,425	1,077	478
955	17,280	18,252	9,900	1,436	638
924	5,760	6,084	3,300	479	213
849	4,320	4,563	2,475	359	159
848	5,760	6,084	3,300	479	213
847	8,640	9,126	4,950	718	319
815	5,760	6,084	3,300	479	213

per vessel. Therefore it was assumed that the towboat engine operated at idle for that three hour period. Since emission calculations in this study were derived in horsepower hours, a methodology similar to that described in Steps 13 thru 22 was used for grid 1078.

4.4.1 Lock 27 Activity

4.4.1.1 Grid #1078 Horsepower Hours - Step 23

The following equations repeated from Section 3.3.3.1 were used to compute hp hours for grid 1078:

$$P_n = \left[(hp \times u_n \times R_c) + (hp \times u_i \times R_i)\right] \times t_n \times \frac{d}{S_n} \quad \text{(Eq. 4)}$$

$$P_s = \left[(hp \times u_s \times R_c) + (hp \times u_i \times R_i)\right] \times t_s \times \frac{d}{S_s} \quad \text{(Eq. 5)}$$

where:

P_n, P_s = total hp hours for grid for northbound (P_n) and southbound (P_s) traffic

hp = average hp per towboat

u_n, u_s = average hp utilized northbound (u_n) and southbound (u_s)

u_i = hp utilized when engine is at idle

R_c = fraction of day towboats are not at idle in the grid

R_i = fraction of day towboats are at idle in the grid

t_n, t_s = traffic volume northbound (t_n) and southbound (t_s)

d = grid distance in kilometers

S_n, S_s = average towboats speed northbound (S_n) and southbound (S_s).

The calculations for hp hours for grid 1078 are shown below:

$$P_n = \left[\left(\frac{2000\ \text{hp}\ (.85) \times 7}{8}\right) + \left(\frac{2000\ \text{hp}\ (0)}{8}\right)\right] \times 16 \times \frac{1.2}{5}$$

P_n = 5712 hp hours northbound

$$P_s = \left[\left(\frac{2000\ \text{hp}\ (.5) \times 7}{8}\right) + \left(\frac{2000\ \text{hp}\ (0)}{8}\right)\right] \times 17 \times \frac{1.2}{10}$$

P_s = 1785 hp hours southbound.

4.4.1.2 Emission Rates for Grid #1078 - Step 24

Emission rates for grid 1078 for transit traffic are presented in Tables 8 and 9, columns 6 thru 10. Emission rates for towboats at idle in grid 1078 are calculated below. (Equation is repeated from Section 3.3.3.1.)

$$E_i = h_i \times (t_n + t_s) \times f_i \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots \ \text{(Eq. 5)}$$

where:

E_i = total emissions at idle

h_i = average number of hours towboats delayed at Lock 27 (3 hours)

t_n, t_s = daily traffic volume northbound (t_n) and southbound (t_s) at Lock 27

f_i = emission factors at idle (from Table 11 for CO, NO_x, THC; SO_x, and particulates) are based on large engine fuel consumption estimates.

The application of (Eq. 5) for pollutant NO_x is shown below:

$E_i = 3 \times [16 + 17] \times 95$

E_j = 9405 grams

The results of applying (Eq. 5) for all primary pollutants are presented in Table 15.

TABLE 15. EMISSIONS FOR GRID 1078 FOR TOWBOATS AT IDLE (7,13)

EMISSIONS IN GRAMS PER DAY				
CO	NO_x	THC	SO_x	Part.
154,440	9,405	52,965	27,720	11,880

4.5 EMISSION ESTIMATES

4.5.1 Emission Rates Per Grid - Step 25

Table 16 lists the total emissions per day for each grid. These grids encompass the Mississippi River from Alton, Illinois (mile 197.5) to just above the mouth of the Meramac River (mile 163.5), a total of 34 miles. The data in Table 16 were derived by adding the emission rates from Tables 8 and 9 for transit traffic and Table 14 for port traffic. For grid 1078, the data in Table 15 was also totalled to compensate for Lock 27 transit characteristics.

4.5.2 Port Emissions

The St. Louis Port area stretches for 13 miles along the banks of the Mississippi River from just below Lock 27 to the mouth of the River Des Peres Drainag. Since switching boats operate in that area, the emission density will be higher. Table 17 presents the total emissions in lbs per day and ton per year for the 13 mile port area plus the average emission rate per mile.

TABLE 16. TOTAL EMISSIONS PER GRID IN LBS. OF POLLUTANTS PER DAY

GRID NO.	CO	NO_x	THC	SO_x	Part.
1234	167	433	86	59	26
1233	178	465	92	64	27
1094	117	305	60	42	18
1195	37	96	19	13	6
1166	43	112	22	15	7
1165	74	193	38	26	11
1081	49	128	25	18	8
1132	74	128	25	18	8
1131	25	64	13	9	4
1080	59	154	31	21	9
1079	135	353	70	48	21
1078	405	189	150	84	36
1010	99	219	53	29	12
1040	61	160	32	22	9
1039	68	177	35	24	10
1038	46	160	24	14	6
1074	47	122	24	17	7
1073	80	181	43	24	10
1072	87	187	46	24	10
1071	61	160	32	22	9
1070	61	160	32	22	9
1069	80	181	43	24	10
1068	61	160	32	22	9
1032	10	10	5	1	0
1067	47	122	24	17	7
1031	87	197	46	26	11
1030	109	245	58	32	14
999	35	61	19	7	3
998	125	284	66	37	16
955	127	272	67	35	15

TABLE 16. TOTAL EMISSIONS PER GRID IN LBS. OF POLLUTANTS PER DAY (CONTINUED)

GRID NO.	CO	NO_x	THC	SO_x	Part.
954	16	41	8	6	2
925	36	95	19	13	6
924	97	235	51	31	14
889	24	63	12	9	4
923	36	95	19	13	6
888	61	159	31	22	6
887	79	206	40	28	9
849	28	58	15	7	12
848	85	204	47	24	3
847	92	210	48	25	12
846	30	79	16	11	12
815	39	61	17	8	5
814	73	190	37	23	3
813	127	333	65	46	11
812	157	412	81	56	20
811	79	206	40	28	24
700	157	412	81	56	12
699	218	571	112	78	24
					34
TOTAL	4088	9308	2051	1300	581
Average Per mile	120	274	60	38	17

4.5.3 Total Emissions

Table 18 gives the total emissions for the studied area minus the port area. The table also gives the average emissions per mile for that 21 mile area. Table 19 presents the total emissions for the 34 mile studied area.

TABLE 17. PORT EMISSION ESTIMATES FOR 13 MILE PORT AREA

	CO	NO_x	THC	SO_x	Part.
LBS PER DAY	1,914	4,554	1,004	596	275
TONS PER YEAR	349	831	183	109	50
AVERAGE LBS PER MILE PER DAY	147	350	77	46	21
AVERAGE TONS PER MILE PER YEAR	27	64	14	8	4

TABLE 18. EMISSION ESTIMATES FOR STUDIED AREA EXCLUDING PORT AREA

	CO	NO_x	THC	SO_x	Part.
LBS PER DAY	2,174	4,754	1,047	704	306
TONS PER YEAR	397	868	191	128	56
AVERAGE LBS PER MILE PER DAY	104	226	50	34	15
AVERAGE TONS PER MILE PER YEAR	19	41	9	6	3

TABLE 19. TOTAL EMISSION ESTIMATES FOR 34 MILE STUDIED AREA

	CO	NO_x	THC	SO_x	Part.
LBS PER DAY	4,088	9,308	2,051	1,300	581
TONS PER YEAR	746	1,699	374	237	106

4.6 VESSEL EMISSIONS EXPRESSED IN TERMS OF OTHER SOURCES

4.6.1 Highway Vehicle Miles

The estimated vessel emissions may be more meaningfully expressed in terms of highway vehicle miles emitting the same quantity of air pollutants. A vehicle mile is one vehicle traveling one mile; two vehicles each traveling one-half mile, ten vehicles each traveling one-tenth mile, etc. EPA has published emission factors for typical urban highway driving and vehicle mix,(14) Table 20. The vessel emissions from the 34 mile study area can be expressed as the emissions from same number of highway vehicle miles with the information in Table 20. The equivalent highway vehicle miles are presented in Table 21.

4.6.2 Other

To be included in Final Report.

TABLE 20. AVERAGE EMISSION FACTORS FOR HIGHWAY VEHICLES(14) (BASED UPON AVERAGE ROUTE SPEED OF 19.6 MILES/HOUR AND 1973 VEHICLE MIX)

Pollutant	Emission Factor gm/mile
CO	62
NO_x	5.4
THC	8.5*
SO_x	0.20
Particulates	0.58**

*Includes 2.4 gm/mile crankcase and evaporative emissions.

**Includes 0.20 gm/mile tire wear emissions.

TABLE 21. VESSEL EMISSION EXPRESSED AS EQUIVALENT HIGHWAY VEHICLE MILES

Vehicle Emissions Pollutant	Vehicle Emissions lbs/day	Equivalent Highway Emissions vehicle miles/day
CO	4088	29,900
NO_x	9308	782,000
THC	2051	109,000
SO_x	1300	(2,955,000)*
Particulates	581	(455,000)**

*The difference of sulfur in diesel fuel and gasoline is large and hence the equivalent vehicle miles is large.

**Particulate emissions from diesel engines are of much different composition than particulate emissions from gasoline engines.

5.0 DATA BASE QUALITY

5.1 GENERAL

The vessel exhaust emissions estimated in this study are thought to be the most comprehensive ever for a specific area. Limitations encountered in the study influencing the conclusions include the availability of river vessel traffic information, appropriate vessel duty cycles and operational characteristics, and the usual budget and time constraints of any study.

5.2 VESSEL TRAFFIC

Towboat traffic estimates south of St. Louis were based on aggragate estimates of traffic on the Mississippi between the Missouri and Ohio Rivers, and hence do not have the inherent accuracy of actual vessel counts.

Corps of Engineers' Lock Number 27 has served as an excellent source of information for vessel traffic north of St. Louis. In this draft report, vessel traffic on the Missouri River has not been included. Data are presently being collected so that the split of vessel traffic between the Missouri and Mississippi may be assigned and included in the final report. Seasonal traffic variations will be addressed in the Final Report, with particular attention to periods of flooding and ice jams.

Port traffic allocations are based upon the total port traffic estimates from industry spokesmen(15) and the fact that traffic density within each port grid element is based on the number of terminals within that grid. If these assumptions differ substantially from the actual conditions, the grid elements emission estimates will be erroneous. It was the authors' intent to show the significance of switchboat operations, and the methodology and data used were considered the best available.

5.3 VESSEL DUTY CYCLES

The critical assumption affecting the calculated emissions are the towboat power settings (duty cycles). Any change from the assumed values of 85% maximum power setting for northbound towboats and 50% of maximum power for southbound towboats will cause an almost direct proportional change in exhaust emissions. Similarly, any change in the assumed duty cycle for port traffic will affect the calculated emissions for the respective grids.

6.0 SUMMARY

To be included in the Final Report.

7.0 CONCLUSIONS

To be included in the Final Report.

8.0 REFERENCES

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FUGITIVE DUST METHODOLOGY

December 1974

AIRPORT EMISSION INVENTORY METHODOLOGY

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"This report has been reviewed by the Office of Research and Monitoring, EPA, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use."

ABSTRACT

This report describes a methodology for performing emission inventories at airports, with specific focus on the airports in the St. Louis AQCR. This work was performed in support of EPA's RAPS program. Within the basic methodology, three submethodologies are presented corresponding to municipal, military, and civilian airports. Data collection and handling requirements are discussed, and data for the airports in the St. Louis AQCR are presented. The sensitivity of emission estimates to improved knowledge of data inputs is discussed.

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SECTION I

INTRODUCTION

Under the charges of the Clean Air Act of 1970, the Environmental Protection Agency is assisting state and local pollution control agencies in developing implementation strategies to meet the established air quality standards. A basic premise of these efforts is that operationally a cause and effect relationship between pollution sources and air quality can be accurately specified. The EPA is conducting the Regional Air Pollution Study (RAPS) in St. Louis to determine the current reliability of this premise, and to provide for improvements where accuracy is less than adequate.

To achieve this goal, RAPS will engage in extensive analysis of the atmospheric dispersion and transformation process modeling links between emissions and air pollution levels.[1] The cause and effect data required to analyze these modeling links include detailed temporal and spatial emission inventories; atmospheric data such as wind fields and temperature profiles for dispersion calculations, and insolation data for transformation process modeling; and air pollutant concentration data against which modeling results will be compared.

A crucial phase of this program is the adequate and accurate specification of emission inventories at least to the level of detail engaged by the models - the results of these deterministic links can be no more comprehensive and consistent than the initial input values. Emissions inventories have been made by county in the St. Louis Air Quality Control Region according to the Nation Emissions Data System (NEDS). Air-

Aircraft operations were surveyed for yearly landing and takeoff cycle volumes for each type of airport, and a single emission factor based on type of airport was applied to each to calculate annual emissions. The spatial and temporal detail involved is insufficient for uses other than trend estimates of emissions. This report describes techniques for inventorying airport emissions from aircraft and ground support vehicles and processes as an aid to achieve the RAPS goals.

SECTION II

EMISSION INVENTORY NEEDS FOR RAPS

The St. Louis Interstate Air Quality Control Region is subdivided into a grid system for the RAPS study. The smallest grid side is 1 km, so that an airport may not be wholly enclosed in a single grid. This, and the requirement of hourly average emissions data, dictates the development of more spatially and temporally detailed emission inventory data and methodologies than are currently available.

This report describes the available data and techniques and outlines further refinements of methodologies for inventorying airport emissions. The sources involved include aircraft operations and engine maintenance testing, ground support vehicles, and fuel storage and handling. For these sources there needs to be described:

- emission rate
- emission location
- emission duration

The task of developing and analyzing emission inventory methodologies for these sources can be divided into three sub-tasks based on the type of airport in question; that is, inventories for municipal, civilian, and military airports. The methods for inventorying each are similar and reduce to finding the three factors listed above. However, the types of sources and their significance is a function of the type of airport. The municipal airport has principally commercial jets, ground support vehicles for servicing and fueling these aircraft, jet fuel handling and storage, and testing of jet engines. Civil airports primarily carry private and charter piston aircraft, ground support to the extent of fueling trucks (absent at the smaller airports), gasoline storage and handling (with some jet fuel at larger airports), and testing of piston engines. The military airport operations consist mainly of jet aircraft, fueling trucks, jet fuel handling and storage, and jet engine testing.

SECTION III

FACTORS CONTRIBUTING TO AIRPORT EMISSIONS

The purpose of this section is to outline the factors contributing to airport emissions and to discuss how they are interrelated. This is presented to provide an overview of the inventory problem for airports and to provide a basis from which to examine alternative levels of inventory detail.

The factors contributing to airport emissions are those involved with the previously listed sources of aircraft operation, ground support vehicles, fuel storage and handling, and engine maintenance testing. These factors are discussed for each type of airport in the following sections.

FACTORS AFFECTING FLIGHT OPERATION EMISSIONS

Flight operations consist of the modes listed in Table 1. To determine emissions, two basic factors must be known: (1) the time spent in each mode, and (2) the emission rate for each mode. The interacting factors determining these basic factors are outlined below.

Municipal Airport Flight Operations

Figure 1 is a diagram showing the interactions of factors affecting emission production at a municipal airport. These will be sorted according to significance of contribution and availability of information when levels of emission inventory detail and relative emission contributions are discussed.

Table 1. AIRCRAFT OPERATING MODES[2]

Mode	Engine operating time included in mode
Taxi	Transit times between ramp and apron, apron and runway and time required for turning and alignment between taxiway and runway.
Idle	Push back from gate; waiting for signal to begin taxiing; waiting at taxiway intersections; runway queuing; gate queuing.
Landing	Touchdown to beginning of taxi on taxiway.
Takeoff	After alignment with runway to liftoff.
Approach	3000 ft altitude to touchdown.
Climb-out	Liftoff to 3000 ft altitude.

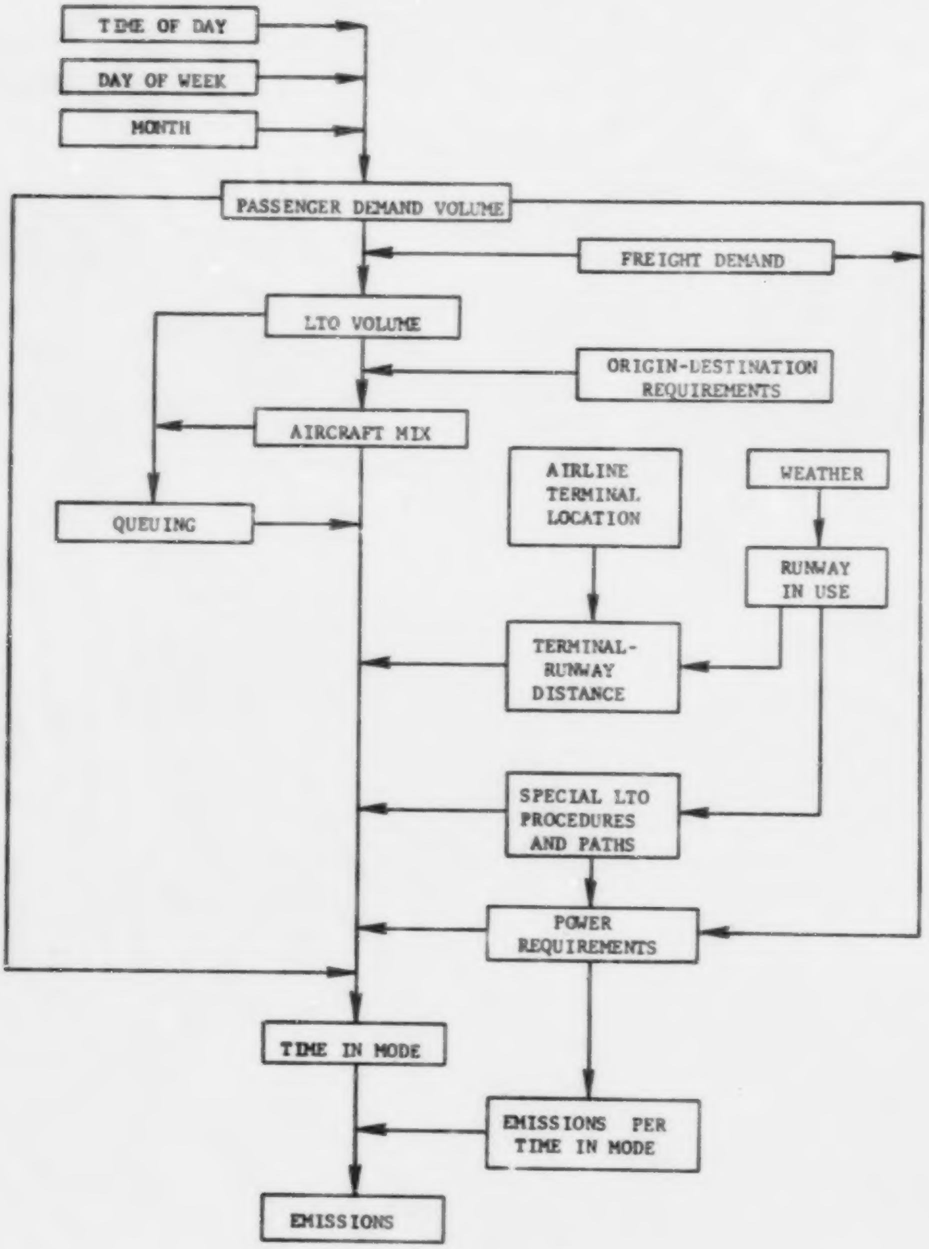
TIME OF DAY
DAY OF WEEK
MONTH
PASSENGER DEMAND VOLUME
FREIGHT DEMAND
LTO VOLUME
ORIGIN-DESTINATION REQUIREMENTS
AIRCRAFT MIX
AIRLINE TERMINAL LOCATION
WEATHER
QUEUING
RUNWAY IN USE
TERMINAL-RUNWAY DISTANCE
SPECIAL LTO PROCEDURES AND PATHS
POWER REQUIREMENTS
TIME IN MODE
EMISSIONS PER TIME IN MODE
EMISSIONS

Figure 1. Interacting factors affecting emissions production at a municipal airport

The major impetus to flight operations is the passenger demand volume. Fluctuations in demand volume occur with time of day, the day of the week, and the month. Figure 2 shows the hourly percent of the total LTO volume for a typical airport. Airline schedules and schedule changes reflect these fluctuations. Freight demands are shown in Figure 1 as being secondary to passenger demands as cargo needs are usually accommodated on passenger flights.

Landing and takeoff cycle volume is then determined by passenger demand. Origin-destination requirements and LTO volume determine the mix of equipment, which in turn feeds back to LTO volume. Short, low passenger demand trips will be made by medium and short range aircraft; longer, high demand trips will use long range and jumbo jets. The aircraft classes and representative aircraft within each class are listed in Table 2.

If the LTO volume is greater than some number characteristic of the airport and runway in use queues will form. The EPA report, "Air Pollution Impact Methodology for Airports," (APTD-1470)[2] recommends adding extra idle time due to queuing as T = (N-30)/10 when the LTO volume exceeds 30 per hour. T is the time queued in minutes and N is the LTO volume. This relationship assumes the use of two parallel runways and is empirically based on experience at Chicago's O'Hare airport. For more nearly accurate idle mode emission calculations, similar relationships should be determined for St. Louis, since in addition to LTO volumes, queue times can depend on airport configuration and runway in use, approach path radio aids, weather, and even the air traffic controller.

The LTO volume affects queuing which affects the time spent in the idle mode. Other "times in modes" are influenced by additional factors as shown in Figure 1.

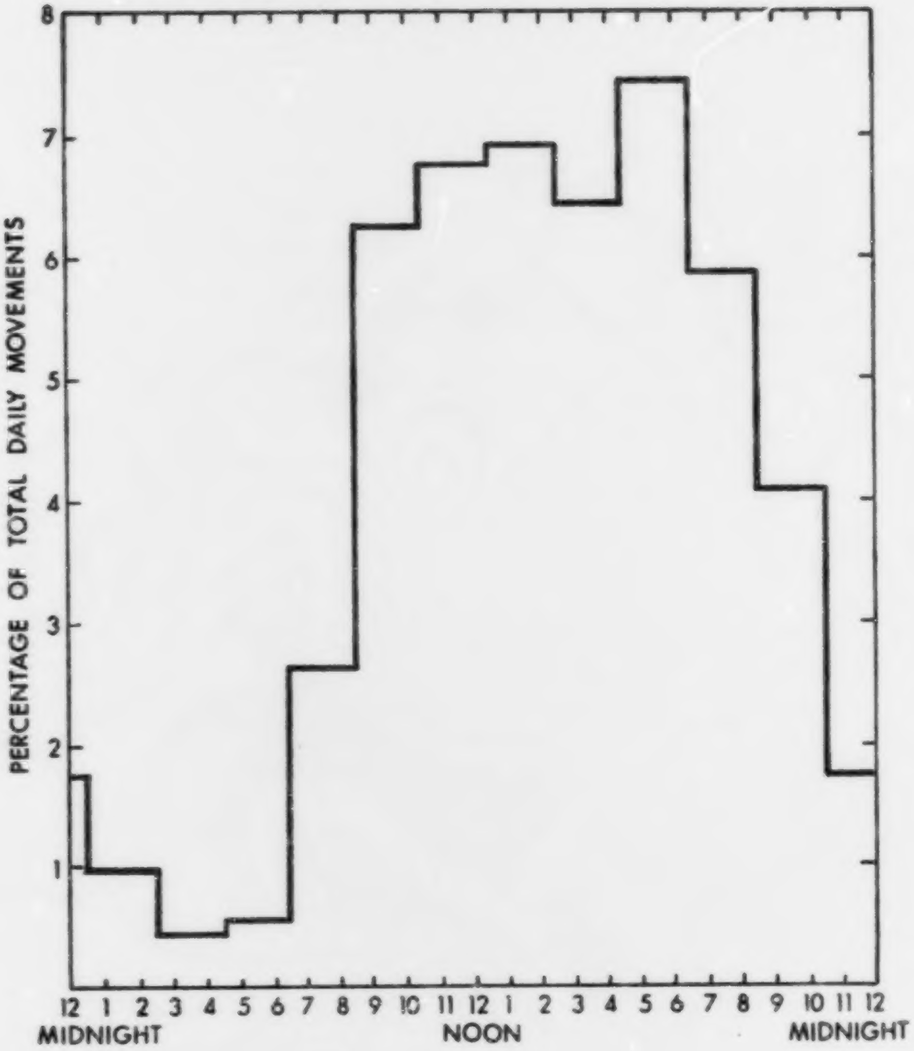

Figure 2. Hourly percent of total daily LTO volume for a typical municipal airport

Table 2. AIRCRAFT CLASSIFICATIONS AND REPRESENTATIVE AIRCRAFT[3]

Aircraft class	Representative aircraft
Jumbo jet	Boeing 747 Lockheed L-1011 McDonald Douglas DC-10
Long-range jet	Boeing 707 McDonald Douglas DC-8
Medium-range jet	Boeing 727 Boeing 737 McDonald Douglas DC-9
Air carrier turboprop	Convair 580 Electra L-188 Fairchild Hiller FH-227
Business jet	Gates Learjet Lockheed Jetstar
General aviation turboprop	-
General aviation piston	Cessna 210 Piper 32-300
Piston transport	Douglas DC-6
Helicopter	Sikorksy S-61 Vertol 107
Military turboprop	
Military jet	
Military piston	

Meteorological conditions of wind direction and visibility determine the runway in use. Generally, it will be the longest runway or the one most nearly parallel to wind direction, although low visibility or night flight might require the use of an instrument landing system equipped or lighted runway which does not give the best alignment with wind direction. The terminal location and the runway in use determine the time spent in taxi mode before takeoff and after landing.

Time in takeoff and landing modes is affected by the component of wind velocity parallel to the runway and by the temperature as well as type of aircraft. Takeoff and landing times are shorter the higher the wind speed and the lower the temperature. These times become longer as the aircraft carries more mass to be accelerated and lifted, or decelerated after landing.

The same factors affect climbout and approach, with potential modifications if nearby populated areas require special noise reduction procedures and flight paths. These may include techniques such as climbing at reduced power and immediate turns away densely populated areas.

After the time spent in the different modes are determined they can be multiplied by the modal emission rates to calculate emissions. The emission rates depend basically on power requirements and engine type, which are in turn related to passenger and freight volume, amount of fuel carried for origin-destination requirements, weather, and special LTO procedures.

Civilian Airport Flight Operations

Figure 3 is a diagram of the interacting factors involved in emission production at a civilian airport. Weather is a dominant factor in civilian flight operations. The level of activity falls as the weather deteriorates, since much of the flying done is for instruction and pleasure, and since pilot qualifications often exclude flying during

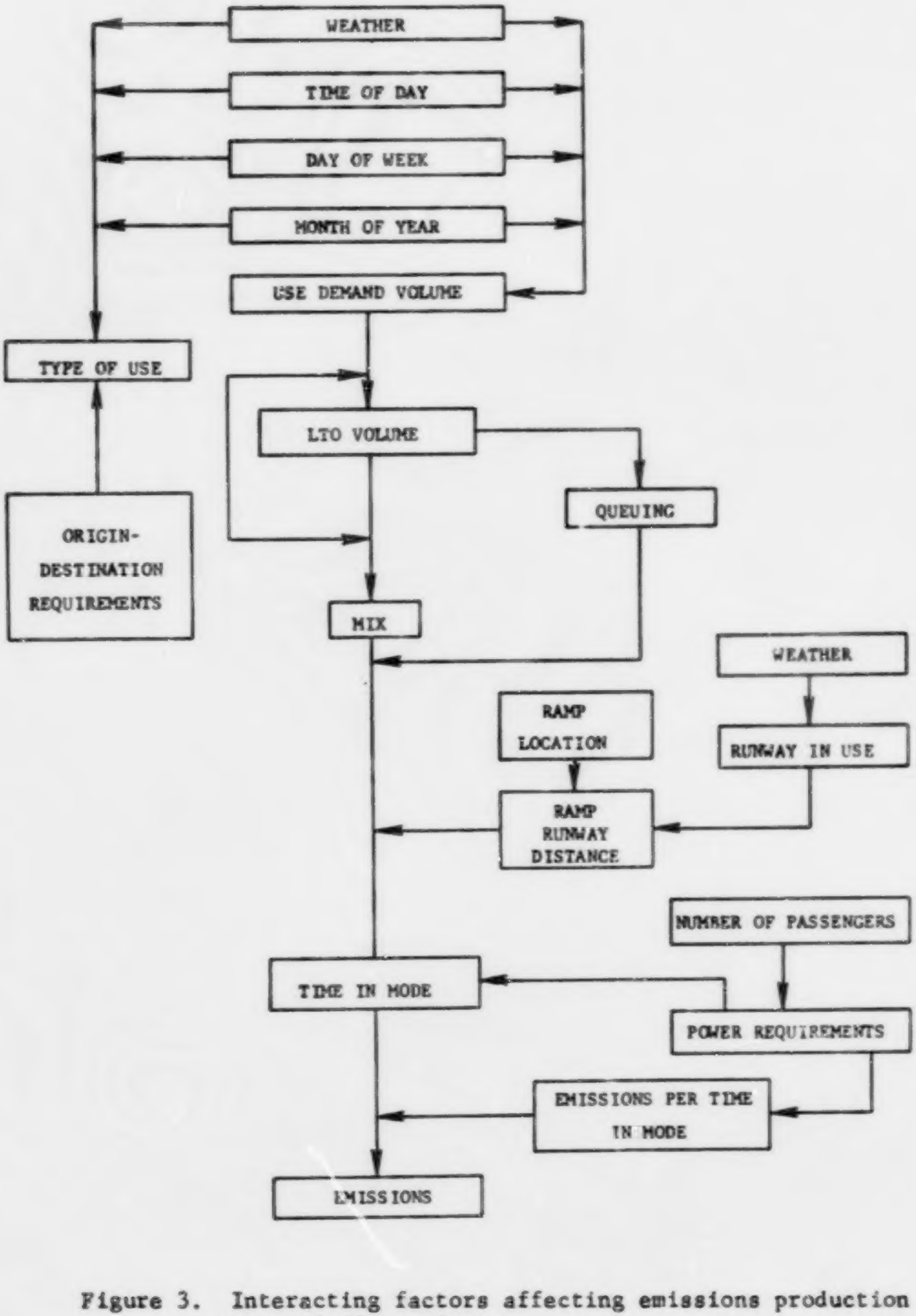
WEATHER
TIME OF DAY
DAY OF WEEK
MONTH OF YEAR
USE DEMAND VOLUME
TYPE OF USE
LTO VOLUME
QUEUING
ORIGIN-DESTINATION REQUIREMENTS
MIX
WEATHER
RAMP LOCATION
RUNWAY IN USE
RAMP RUNWAY DISTANCE
NUMBER OF PASSENGERS
TIME IN MODE
POWER REQUIREMENTS
EMISSIONS PER TIME IN MODE
EMISSIONS

Figure 3. Interacting factors affecting emissions production at a civilian airport

inclement weather. Further, the airport may not be equipped with the radio navigation aids needed for foul weather flying.

The traffic volume also varies with time of day, day of week, and month. It is generally heavier in the evening, on weekends, and in the summer when private pilots have the time and weather offers more incentive to fly.

These factors determine the air traffic volume and, to some extent, the mix. Commercial charter and business flights are less affected by weather than private flights. When there is a large percentage of private flights the mix will have a greater percentage of small, single engine aircraft.

Time in mode is affected by the same factors as at the municipal airport, only in this case the aircraft are at ramp or tie-down locations. Aircraft rental, instruction, and charter companies generally have a specific portion of the ramp area for their use which is rented from the airport authority. These locations can be determined from a visit to the airport.

Time in mode, and also power requirements, are further affected by the number of passengers, especially in light, two or four-place planes where passenger weight is a significant fraction of aircraft weight. Climbout time is reduced with fewer passengers, reducing time in this mode, while approach time is increased because of reduced downward weighting force.

When emission rates as functions of mode and power requirements are known, they can be multiplied by the times in the various modes to find emissions.

Military Airport Flight Operations

These operations are influenced by the factors common to all airport operations; however, they are not dependent on passenger demands, as at the municipal airport, nor are they strongly affected by weather, as for civilian flights. The level of activity is determined mainly by training, proficiency, and defense requirements. Weather determines the runway used and taxi times.

FACTORS AFFECTING GROUND SUPPORT VEHICLE EMISSIONS

Municipal Airport

The municipal airport has by far the most ground service vehicle operations. A listing of the types of service vehicles is given in Table 3. The extent of use of each vehicle is directly related to LTO volume and aircraft mix. Emissions can be calculated from published data on service times and emission rates. Emissions from service vehicle travel around the airport can be found knowing the airport layout, the activity, and the proper emission factors.

Civilian Airports

Service vehicles at civilian airports are almost exclusively fueling trucks, and even these may be absent at the smaller airports. Other support vehicles may include tractors, etc. for grass cutting and snow removal.

Military Airport

Service vehicles at the military airport also include fueling trucks and many of the vehicles found at municipal airports. Emissions from these sources are dependent on flight activity.

Table 3. SERVICE VEHICLES USED AT A MUNICIPAL AIRPORT[2]

	Vehicle
1.	Tractor
2.	Belt loader
3.	Container loader
4.	Cabin service
5.	Lavatory truck
6.	Water truck
7.	Food truck
8.	Fuel truck
9.	Tow tractor
10.	Conditioner
11.	Airstart
	Transporting engine Diesel power unit
12.	Ground power unit
	Transporting engine Gasoline power unit Diesel power unit
13.	Transporter

FUEL HANDLING AND STORAGE EMISSIONS

These emissions are of two types: (1) working losses, and (2) breathing losses. The former type occurs when vapors in fuel tanks are displaced during fueling, and when there is spillage and evaporation. The latter type is due to diurnal temperature variations, wind speeds, and fuel vapor pressure among other factors. It may be controlled by tank vapor recovery systems.

Municipal Airport

By far the largest use is of jet fuel with a much smaller volume of gasoline used for service vehicles and piston aircraft. Actual volumes of each are a function of LTO activity, passenger volumes, and origin-destination distances.

Civilian Airport

Here, gasoline comprises the larger volume of fuel use. Jet fuel is available at the larger airports. Gasolines of different octane ratings at these airports will have slightly different emission characteristics because of volatility differences. Actual use will be determined by LTO activity and the factors affecting it.

Military Airport

Jet fuel comprises the larger use for military airport operations. Gasoline is used for service vehicles.

ENGINE MAINTENANCE TESTING

The emissions from this source depend on the test cycle power settings and times spent at each setting for the various types of engines. The municipal and military airports will handle mostly jet engine testing, while the civilian airports will test piston engines. Emissions from this source at the smaller civilian airports will be negligible, if not non-existent.

SECTION IV

LEVELS OF EMISSION INVENTORY DETAIL

The ideal emissions inventory would consider all the interrelating factors described in Section III. Of course, the time and economic costs would be prohibitive. The purpose of this study is to consider alternative levels of detail for making inventories on a "cost-benefit" basis, determining the significance of emissions sources and the sensitivity of an inventory in return for added data collection and analysis efforts. In this section, levels of detail are outlined with comments on efforts and benefits.

EMISSIONS INVENTORY FROM PUBLISHED DATA

Features:

- NEDS data on annual LTO volumes by airport type and county
- Uses average emission factor for LTO cycle based on type of airport
- Annual LTO activity data available from FAA
- Time resolution - annual average
- Spatial resolution - countywide area source

Comments:

- Easily calculated from readily available data
- Insufficient resolution and specificity by source.

TYPE OF AIRCRAFT DETAIL

Features:

- Emission factor for type of aircraft
- Percent of total LTO's for type of aircraft
- Emission factor for service vehicle use by type of aircraft
- Emission factor for fuel handling and storage by aircraft mix and total LTO's
- Emission factor for maintenance testing by type of aircraft
- Data available from FAA, airport records, airline schedules
- Time resolution - by type of data collected
- Spatial resolution - by source locations at airport

Comments:

- More extensive data collection effort
- Easily calculated once necessary data are known
- Time resolution variable

TIME-IN-MODE DETAIL

Features:

- Emission factors by mode required
- Average times in mode required

Comments:

- Average time in mode data available from EPA publication "An Air Pollution Impact Methodology for Airports - Phase I," (APTD-1470)
- No additional data collection needed
- Relatively little added effort over type of aircraft detail

HOURLY EMISSION ESTIMATES

Features:

- LTO activity by time of day, day of week, month, type of aircraft
- Data available from airline schedules, airport records, FAA

Comments:

- Extensive effort required for data collection and analysis over time-in-mode detail
- Hourly resolution for aircraft operations, support vehicles, fuel handling

REFINED HOURLY EMISSIONS ESTIMATES

Features:

- To include meteorological effects, special LTO procedures, aircraft loading, terminal-runway distances, queuing

Comments:

- Long-term, extensive effort required for data collection
- Computer analysis of data
- Degree of refinement not initially required

RELATIVE EMISSIONS CONTRIBUTIONS BY SOURCE AT AIRPORTS

Table 4 shows the relative emissions contributions of the airport sources at O'Hare airport in 1970. Aircraft operations account for well over 60 percent of carbon monoxide and hydrocarbon emissions, and about 90 percent of these emissions occurs during taxi and idle modes. This indicates a good sensitivity return for improved data on time in mode and emission rates for these modes.

Table 4. PERCENT EMISSIONS CONTRIBUTION BY SOURCE AT O'HARE AIRPORT - 1970

Source	CO	HC	NO_x	Particulate
Aircraft	69	79	86	96
Service vehicles	31	13	14	4
Fuel handling	0	8	0	0

Aircraft operations contribute 86 percent to total NO_x emissions, indicating good leverage from improved information on the factors involved. Most of these emissions occur during the high power operations of takeoff and climbout.

SECTION V

EMISSION ESTIMATION METHODOLOGY FOR LAMBERT FIELD

This section and the following two sections describe the hourly emission estimation techniques. This section applies to Lambert Field, the next one applies to Scott AFB, and Section VII describes the methodology for the civilian airports. The three types of airports are discussed separately, since data availability and the complexity of the required methodology is different for each. Four emission sources are included in the methdologies:

- Aircraft flight operations
- Ground service vehicles
- Fuel handling and storage
- Engine testing and maintenance.

EMISSIONS FROM AIRCRAFT FLIGHT OPERATIONS

To estimate hourly emissions from aircraft flight operations five parameters must be known:

- Temporal activity patterns
- Spatial activity patterns
- Percent volume distribution of aircraft types
- Time spent in the different operating modes
- Emission factors.

The following sections discuss the availability of data for each of these five parameters, and the use of these data in a methodology for emission estimation.

Temporal Activity Patterns

Ideally, hourly landing and takeoff volumes and type of equipment would be known for the best predictions of emissions. However, this information is not compiled and estimates must be made from available data.

For Lambert Field there are three sources of data:

- Federal Aviation Administration Air Traffic Control Tower, Mr. Jerome C. Moonier
- Lambert Field, Manager's Office, Mr. Arthur K. Muchmore, Assistant Airport Manager, Operations and Maintenance
- Official Airline Guide[4] listings for air carrier traffic at St. Louis

The FAA maintains daily totals of traffic volumes under the classifications shown in Table 5. Local traffic has its origin and destination at Lambert, and it mainly involves "touch and go" landing and takeoff practice. Itinerant operations have their origin or destination at another airport. These classifications are further divided for itinerant traffic into air carrier, air taxi, general aviation, and military categories. For local operations they are subdivided into civilian and military categories. The FAA also compiles average hourly activity totals for May and November. The November totals are presented in Table 6.

The airport manager's office receives its flight activity information from the FAA in the form described. This office is an alternative source of this information.

Table 5. FAA CLASSIFICATION OF DAILY AIR TRAFFIC OPERATIONS

	Itinerant air traffic					Local air traffic			Total air traffic
DAY	AIR CARRIER	AIR TAXI	GENERAL AVIATION	MILITARY	TOTAL	CIVIL	MILITARY	TOTAL	

Table 6. AVERAGE HOURLY AIR TRAFFIC VOLUMES AT LAMBERT FIELD, ST. LOUIS, FOR MAY AND NOVEMBER, 1972

Hour	Volume
0000-0100	12
0100-0200	11
0200-0300	10
0300-0400	3
0400-0500	4
0500-0600	5
0600-0700	13
0700-0800	36
0800-0900	55
0900-1000	64
1000-1100	68
1100-1200	66
1200-1300	64
1300-1400	66
1400-1500	65
1500-1600	57
1600-1700	67
1700-1800	64
1800-1900	50
1900-2000	43
2000-2100	40
2100-2200	26
2200-2300	30
2300-2400	13

The Official Airline Guide lists flight schedules semi-monthly for the air carriers. These listings show scheduled departure and arrival times and type of aircraft used. Scheduled flight activity to St. Louis is listed in one section of the Guide, while flights from St. Louis to other cities are listed under the destination city headings.

Table 6 lists hourly totals of flight activity at Lambert Field. To complete the temporal data, the total volumes by month and by the day of the week for the four aircraft categories are given in Tables 7 and 8. The itinerant and local volumes have been combined for both general aviation and military flights in these Tables.

In order to prepare a methodology for estimating emissions, the volumes given in Tables 6, 7, and 8 were converted to percentages totaling 100 percent for each category of aircraft. The computed percentages for monthly, daily, and hourly air traffic are given in Tables 9, 10, and 11.

To compute the volume of traffic for category i for a given hour, day, and month we start from the relationship:

$$V_i = \frac{A_i' \cdot M_i \cdot D_i \cdot H_i}{(OD_m)\ (10^6)}$$

where i indicates the category (e.g. air carrier), A_i' is the annual volume, and M_i, D_i, and H_i are the percents of the annual volume for the month, day, and hour of interest. The factor OD_m is the average occurrence of the day of the week for the month. It equals 4.43 for months having 31 days, 4.29 for 30 day months, and 4 for February (4.14 in a leap year). The factor of 10^6 converts the percentages to decimals. This relationship can be entered at any point. For example, if the monthly total is known,

Table 7. MONTHLY AIR TRAFFIC AT LAMBERT FIELD, ST. LOUIS, FOR DECEMBER 1972 AND JANUARY - NOVEMBER 1973

Month	Air carrier	Air taxi	General aviation	Military	Total
January	16,006	1,985	9,112	1,008	28,111
February	14,316	1,744	8,957	1,013	26,030
March	15,655	2,052	9,300	1,071	28,078
April	13,955	2,078	11,305	1,363	28,701
May	12,236	2,606	13,106	1,576	29,524
June	12,363	2,648	12,618	1,293	28,922
July	15,703	2,492	12,137	963	31,295
August	16,721	2,812	12,420	1,187	33,140
September	15,934	2,474	10,509	1,106	30,023
October	16,658	2,724	11,985	1,353	32,720
November	11,004	2,488	11,110	878	25,480
December	15,234	1,590	6,691	861	24,376
Category Total	175,785	27,693	129,250	13,672	346,400

Table 8. AIR TRAFFIC VOLUMES BY DAY OF WEEK AT LAMBERT FIELD, ST. LOUIS, FOR DECEMBER 1972 AND JANUARY - NOVEMBER 1973

Day	Air carrier	Air taxi	General aviation	Military	Total
Sunday	23,385	1,907	15,851	1,096	42,239
Monday	25,037	3,229	15,369	1,219	44,854
Tuesday	25,499	4,801	18,424	2,266	50,990
Wednesday	25,965	5,115	20,772	2,532	54,384
Thursday	26,259	5,040	21,326	2,390	55,015
Friday	26,718	5,280	20,499	2,505	55,002
Saturday	22,922	2,321	17,009	1,664	43,916
Category Total	175,785	27,693	129,250	13,672	346,400

Table 9. PERCENT OF TOTAL ANNUAL AIR TRAFFIC BY MONTH AT LAMBERT FIELD

Month	Air carrier	Air taxi	General aviation	Military	Total
January	9.11	7.17	7.05	7.37	8.18
February	8.14	6.30	6.93	7.41	7.57
March	8.91	7.41	7.20	7.83	8.16
April	7.94	7.50	8.75	9.97	8.07
May	6.96	9.41	10.14	11.53	8.52
June	7.03	9.56	9.76	9.46	8.38
July	8.93	9.00	9.39	7.04	8.98
August	9.51	10.15	9.61	8.68	9.64
September	9.06	8.93	8.13	8.09	8.73
October	9.48	9.84	9.27	9.90	9.52
November	6.26	8.96	8.60	6.42	7.40
December	8.67	5.74	5.18	6.30	6.86

Table 10. PERCENT OF TOTAL AIR TRAFFIC BY DAY OF WEEK FOR LAMBERT FIELD, ST. LOUIS

Day	Air carrier	Air taxi	General aviation	Military	Total
Sunday	13.30	6.89	12.26	8.02	12.19
Monday	14.24	11.66	11.89	8.92	12.95
Tuesday	14.51	17.34	14.25	16.57	14.72
Wednesday	14.77	18.47	16.07	18.52	15.70
Thursday	14.94	18.20	16.50	17.48	15.88
Friday	15.20	19.07	15.86	18.32	15.88
Saturday	13.04	8.38	13.16	12.17	12.68

Table 11. PERCENT OF TOTAL DAILY MOVEMENTS BY HOUR AT LAMBERT FIELD

Hour	Air carrier	Air taxi	General aviation	Military
0000-0100	1.15	2.05	2.05	2.05
0100-0200	1.00	1.33	1.33	1.33
0200-0300	1.00	1.33	1.33	1.33
0300-0400	0.26	0.24	0.24	0.24
0400-0500	0.42	0.24	0.24	0.24
0500-0600	0.42	0.00	0.00	0.00
0600-0700	1.36	0.97	0.97	0.97
0700-0800	3.67	2.54	2.54	2.54
0800-0900	6.02	4.83	4.83	4.83
0900-1000	6.81	5.92	5.92	5.92
1000-1100	6.97	6.88	6.88	6.88
1100-1200	6.86	7.49	7.49	7.49
1200-1300	6.71	6.52	6.52	6.52
1300-1400	7.12	6.88	6.88	6.88
1400-1500	6.60	9.42	9.42	9.42
1500-1600	5.92	8.33	8.33	8.33
1600-1700	7.23	6.76	6.76	6.76
1700-1800	7.18	6.52	6.52	6.52
1800-1900	5.97	5.43	5.43	5.43
1900-2000	5.40	4.35	4.35	4.35
2000-2100	4.71	4.23	4.23	4.23
2100-2200	3.04	3.62	3.62	3.62
2200-2300	2.88	2.66	2.66	2.66
2300-2400	1.31	1.45	1.45	1.45

$$V_i = \frac{M_i' \cdot D_i \cdot H_i}{(OD_m)\ (10^4)}$$

where M_i' is the monthly total volume of aircraft category i.

Suppose it is required to estimate the air carrier activity between 10 am. and 11 am. on a Wednesday in June. The arrival total $A_i' = 175{,}785$; from Table 9, $M_i = 7.03$; $D_i = 14.77$ from Table 10, and $H_i = 6.97$ from Table 11. Hence

$$V_i = \frac{(175{,}785)\ (7.03)\ (14.77)\ (6.97)}{(4.29)\ (10^6)}$$

$$= 30 \text{ air carrier movements (takeoff plus landing).}$$

This method assumes equal numbers of landings and takeoffs, and also that the distribution of activity by month, day of the week, and hour remains constant from year to year. The exact landing and takeoff split by hour for air carriers can be extracted from the Official Airline Guide. This has been done for "average" day, and the results are shown in Table 12. For other categories it is assumed that half the movements are takeoffs and half are landings.

The relationship for calculating hourly volumes can be entered at any point for which a volume is known. The actual volume for the year, month, or day of interest can be used when making an emission inventory retrospectively. These data are available from the FAA Air Traffic Control Tower at Lambert.

The percent volumes presented in Tables 9, 10 and 11 are for December 1972 and January-November 1973. In future years the latest figures could be used to revise these tables either by replacement, or by averaging. The former revision of replacement may become especially

Table 12. PERCENT OF DEPARTURES AND ARRIVALS FOR AIR CARRIER TRAFFIC BY HOUR OF THE DAY[4]

Hour	Departures (%)	Arrivals (%)
0000-0100	25.00	75.00
0100-0200	66.67	33.33
0200-0300	100.00	0
0300-0400	0	100.00
0400-0500	0	0
0500-0600	100.00	0
0600-0700	33.33	66.67
0700-0800	58.33	41.67
0800-0900	52.94	47.06
0900-1000	37.84	62.16
1000-1100	60.53	39.47
1100-1200	40.63	59.37
1200-1300	43.59	56.41
1300-1400	32.26	67.74
1400-1500	62.86	37.14
1500-1600	32.00	68.00
1600-1700	42.11	57.89
1700-1800	50.00	50.00
1800-1900	40.63	59.37
1900-2000	51.43	48.57
2000-2100	41.67	58.33
2100-2200	15.38	84.62
2200-2300	20.00	80.00
2300-2400	57.14	42.86

important if economic or other factors change the distribution as well as the total volume of air traffic.

Spatial Patterns of Aircraft Flight Activity

Aircraft flight activity consists of the six modes described in Table 1. These modes occur at different locations on the airport, and the emissions estimates must reflect this spatial variation. Lambert Field lies in eight grid elements of 1 kilometer squared according to the grid network designed for RAPS. Table 13 displays the grid numbers, the grid coordinates, and the aircraft operations in each grid according to the runway being used. Figure 4 shows the grids overlaid on the airport. No grids are listed for climbout or approach; these are listed later with times in mode. Lambert Field requests that aircraft maintain a constant heading away from or towards the runway when flying below 1500 feet. The approach glide path is about 2.5 or 3 degrees, so an approach heading is maintained within a distance of about 5 miles from the airport. The FAA indicates good compliance with this request. Above 1500 feet the aircraft may fly in any direction.

As an example, consider the emissions from the hourly volume of 30 air carrier movements. For the 1000-1100 hour, approximately 60 percent of these aircraft are departing. Generally these aircraft will move from the terminal area to the runway by the most direct taxiway when departing, and they will move from the runway to the terminal area by the shortest taxi distance after landing. In this example, it is assumed that runway 30L is the active runway. Referring to Figure 4, two thirds of the terminal area, or ramp, is in grid 523, while the other third is in grid 492. Aircraft will taxi out to take off in grids 492, 523, and 559, and take off in grids 560, 523, and 559. (See Table 13.) Of the 18 aircraft taking off, 12 will have idle mode emissions in grid 523, and 6 will emit during idle in grid 492. The simplest method of distributing the taxi and takeoff emissions would be to divide them equally

Table 13. OPERATING MODES FOR EACH GRID BY ACTIVE RUNWAY AT LAMBERT FIELD, ST. LOUIS

Runway	Grid	X-Coord	Y-Coord	Size	Idle	Taxi	Takeoff	Climbout	Approach	Landing	Taxi
30L	560	4291	730	1	x		x			x	
	559	4290	730	1	x	x	x				
	523	4291	729	1	x	x	x			x	x
	493	4292	728	1			x			x	x
	492	4291	728	1	x	x				x	x
	452	4292	727	1							
30R	560			1	x	x	x			x	
	524	4292	729	1		x	x			x	
	523			1		x	x			x	x
	493			1	x	x	x			x	x
	492			1	x	x					x
	452			1							
12R	560										
	523				x	x	x			x	x
	493				x	x	x			x	x
	492				x	x	x			x	x
	452				x	x	x			x	
12L	560										
	524					x	x			x	
	523					x	x			x	x
	493				x	x	x			x	
	492										
35	524					x	x			x	x
	523				x	x	x			x	x
	493				x	x					x
17	524				x	x	x			x	
	523					x	x			x	x
	493				x	x					x

Table 13 (continued). OPERATING MODES FOR EACH GRID BY ACTIVE RUNWAY AT LAMBERT FIELD, ST. LOUIS

Runway	Grid	X-Coord	Y-Coord	Size	Idle	Taxi	Takeoff	Climbout	Approach	Landing	Taxi
6	524					x					
	523										
	493				x	x	x			x	
	492				x	x					x
	452				x	x					x
	451	4291	727			x	x			x	
24	524				x	x	x			x	
	523					x					x
	493				x	x	x			x	x
	492				x	x					x
	451				x		x			x	x

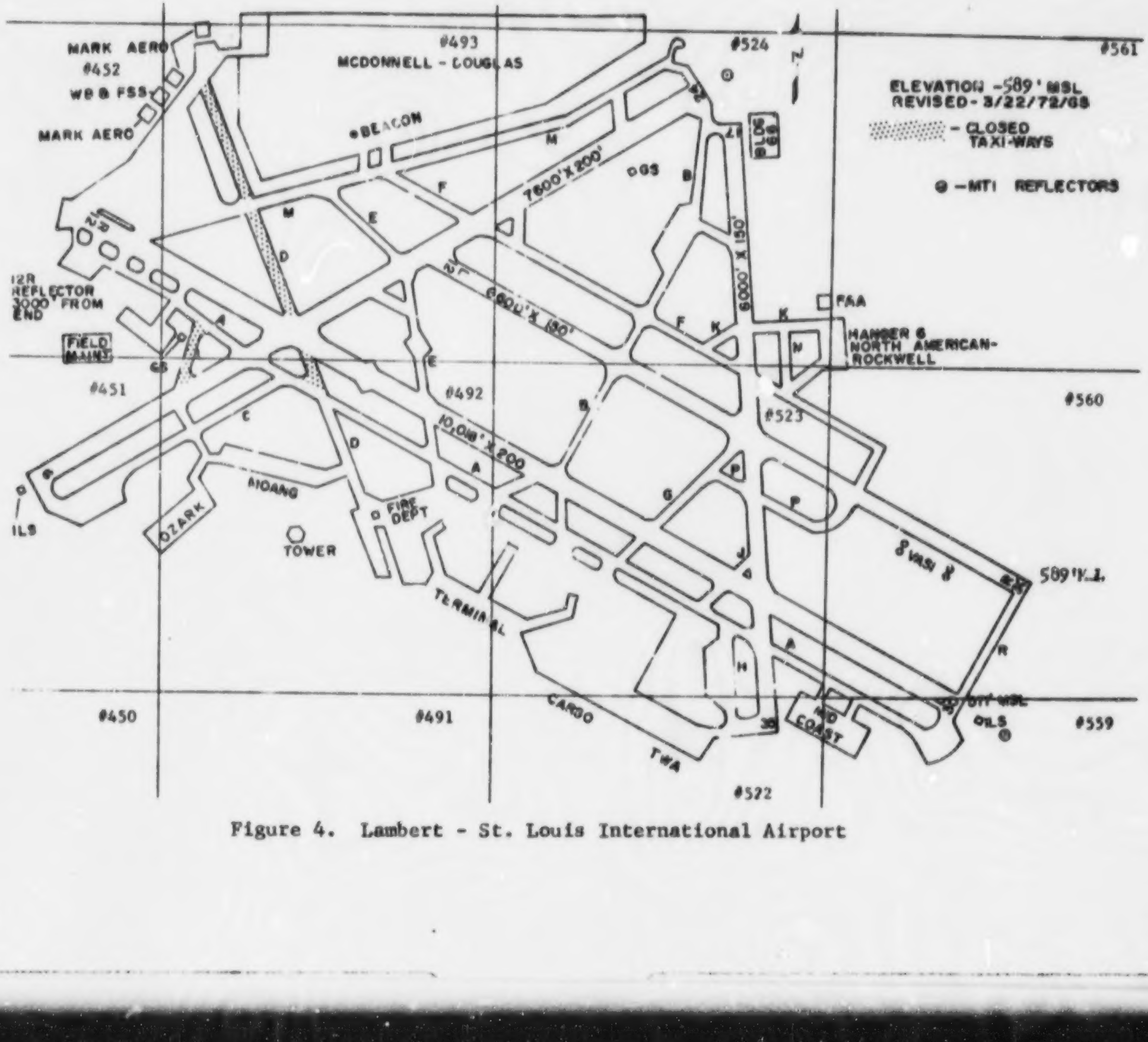
MARK AERO
#452
WB & FSS
MARK AERO
#493
MCDONNELL - DOUGLAS
BEACON
#524
N
#561
ELEVATION - 589' MSL
REVISED - 3/22/72/GS
- CLOSED TAXI-WAYS
- MTI REFLECTORS
BLDG 69
7600'X200'
6000' X 150'
6600'X 150'
10,018' X 200
GS
FAA
HANGER 6
NORTH AMERICAN-ROCKWELL
12R REFLECTOR 3000' FROM END
FIELD MAINT
#451
#492
#523
#560
A
B
C
D
E
F
G
H
J
K
M
N
P
R
ANG
TOWER
FIRE DEPT
OZARK
ILS
TERMINAL
CARGO
TWA
MID COAST
VASI
589'V.I.
OM MM
OILS
#450
#491
#522
#559
12R
30L
6R
24
17
35
12L

Figure 4. Lambert - St. Louis International Airport

among the grids involved. A more refined yet still simple method would be weight them according to the percent of the total taxi or takeoff time spent in each grid. This method is described here.

Table 14 shows the times in mode in each grid for air carriers taxiing to and taking off from runway 30L. To calculate emissions for each grid, the idle emissions are added to grids 492 and 523 for the six and 12 aircraft, respectively, the taxi emissions are distributed by the times in Table 14 for the six aircraft starting from grid 492 and the 12 starting from 523, and the takeoff emissions from all 18 aircraft are distributed in the grids containing runway 30L. This same method is used for landing and taxiing to the terminal area and for other runways and ramp destinations. Tables 15 through 21 list the times in mode by grid and by mode for the aircraft categories using the remaining runways.

A complicating factor is the queuing of aircraft waiting to take off during periods of heavy volume. The EPA report APTD-1470 recommends adding extra idle time due to queuing as T = (N-30)/10 when the landing and takeoff volume exceeds 30 per hour. T is the time queued (minutes) and N is the LTO volume. This relationship is based on data from Chicago's O'Hare airport and assumes the use of two parallel runways. Observation at Lambert Field indicate, however, that no extensive queuing occurs ever during periods of heaviest volume.

Emission Rates

Most emission rate data for aircraft have been gathered by the Cornell Aeronautical Laboratory. These are compiled in the report "Analysis of Aircraft Exhaust Emission Measurements," (PB-204-879)[5] and summarized in the EPA report "Compilation of Air Pollutant Emission Factors," (AP-42).[3] Emission rates for SO_2 are not given, possibly because of variation with fuel sulfur content, but they can be estimated by the product of the fuel use rate and the percent of sulfur in the fuel.

Table 14. TIMES IN MODE BY GRID BY MODE FOR AIR TRAFFIC USING RUNWAY 30L (seconds)

	Air carrier						Military					
Grid	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach
2187	0	0	0	0	35	0	0	0	0	0	10	0
683	0	0	0	0	0	26	0	0	0	0	0	15
654	0	0	0	0	0	26	0	0	0	0	0	15
653	0	0	0	0	0	26	0	0	0	0	0	15
616	0	0	0	0	0	26	0	0	0	0	0	15
589	0	0	0	0	0	26	0	0	0	0	0	15
588	0	0	0	0	0	26	0	0	0	0	0	15
560	20	0	10	0	0	3	0	0	10	4	0	2
559	45	15	2	0	0	7	130	30	0	0	0	4
524	0	0	0	0	0	0	0	0	0	0	0	0
523	540	130	30	20	3	0	150	120	14	20	0	0
522	0	0	0	0	0	0	0	0	0	0	0	0
493	0	0	0	0	15	0	0	0	0	0	8	0
492	520	230	0	15	5	0	200	150	0	0	0	0
452	0	0	0	0	15	0	0	0	0	0	2	0
451	0	0	0	0	0	0	0	0	0	0	0	0
389	0	0	0	0	35	0	0	0	0	0	10	0

Table 15. TIMES IN MODE BY GRID BY MODE FOR AIR TRAFFIC USING RUNWAY 12R
(seconds)

	Air carrier						Military					
Grid	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach
2187	0	0	0	0	0	68	0	0	0	0	0	45
683	0	0	0	0	13	0	0	0	0	0	0	0
654	0	0	0	0	13	0	0	0	0	0	6	0
653	0	0	0	0	13	0	0	0	0	0	0	0
616	0	0	0	0	13	0	0	0	0	0	6	0
589	0	0	0	0	13	0	0	0	0	0	6	0
588	0	0	0	0	13	0	0	0	0	0	0	0
560	0	0	0	0	4	0	0	0	0	0	2	0
559	0	0	0	0	10	0	0	0	0	0	4	0
524	0	0	0	0	0	0	0	0	0	0	0	0
523	524	210	2	10	15	0	0	40	8	8	6	0
522	0	0	0	0	0	0	0	0	0	0	0	0
493	15	45	20	5	0	5	60	70	8	8	0	0
492	520	110	10	20	0	0	420	50	8	8	0	0
452	45	15	10	0	0	5	0	0	0	0	0	6
451	0	0	0	0	0	0	0	0	0	0	0	0
389	0	0	0	0	0	68	0	0	0	0	0	45

Table 16. TIMES IN MODE BY GRID BY MODE FOR AIR TRAFFIC USING RUNWAY 30R
(seconds)

	Air taxi						General aviation					
Grid	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach
560	150	0	0	15	0	273	100	0	0	9	0	360
559	0	0	0	0	0	0	0	0	0	0	0	0
524	0	80	13	0	0	0	0	80	8	0	0	0
523	0	80	20	18	0	0	0	80	20	18	0	0
522	0	0	0	0	0	0	0	0	0	0	0	0
493	600	320	0	0	200	0	500	320	0	0	250	0
492	0	0	0	0	0	0	0	0	0	0	0	0
452	0	0	0	0	25	0	0	0	0	0	50	0
451	0	0	0	0	0	0	0	0	0	0	0	0

Table 17. TIMES IN MODE BY GRID BY MODE FOR AIR TRAFFIC USING RUNWAY 12L
(seconds)

	Air taxi						General aviation					
Grid	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach
560	0	0	0	0	225	0	0	0	0	0	300	0
559	0	0	0	0	0	0	0	0	0	0	0	0
524	0	90	17	17	0	0	0	90	10	9	0	0
523	0	90	16	16	0	0	0	90	8	9	0	0
522	0	0	0	0	0	0	0	0	0	0	0	0
493	750	300	0	0	0	123	600	300	0	0	0	160
492	0	0	0	0	0	0	0	0	0	0	0	0
452	0	0	0	0	0	150	0	0	0	0	0	200
451	0	0	0	0	0	0	0	0	0	0	0	0

Table 18. TIMES IN MODE BY GRID BY MODE FOR AIR TRAFFIC USING RUNWAY 35
(seconds)

	Air taxi						General aviation					
Grid	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach
560	0	0	0	0	0	0	0	0	0	0	0	0
559	0	0	0	0	0	0	0	0	0	0	0	0
524	0	160	0	0	225	0	0	160	0	0	300	0
523	250	160	33	33	0	0	50	160	18	18	0	0
522	0	44	0	0	0	273	0	44	0	0	0	360
493	500	300	0	0	0	0	450	300	0	0	0	0
492	0	0	0	0	0	0	0	0	0	0	0	0
452	0	0	0	0	0	0	0	0	0	0	0	0
451	0	0	0	0	0	0	0	0	0	0	0	0

Table 19. TIMES IN MODE BY GRID BY MODE FOR AIR TRAFFIC USING RUNWAY 17
(seconds)

	Air taxi						General aviation					
Grid	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach
560	0	0	0	0	0	0	0	0	0	0	0	0
559	0	0	0	0	0	0	0	0	0	0	0	0
524	250	100	30	30	0	273	50	100	15	15	0	360
523	0	100	3	3	40	0	0	100	0	0	50	0
522	0	0	0	0	185	0	0	0	0	0	250	0
493	500	380	0	0	0	0	450	380	0	0	0	0
492	0	0	0	0	0	0	0	0	0	0	0	0
452	0	0	0	0	0	0	0	0	0	0	0	0
451	0	0	0	0	0	0	0	0	0	0	0	0

Table 20. TIMES IN MODE BY GRID BY MODE FOR AIR TRAFFIC USING RUNWAY 6
(seconds)

	Air taxi						General aviation						Military					
Grid	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach
560	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
559	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
524	0	0	0	0	125	0	0	0	0	0	175	0	0	50	0	0	25	0
523	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
522	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
493	300	290	10	11	100	0	250	290	8	6	125	0	0	0	20	20	5	0
492	0	10	10	11	0	0	0	10	5	6	0	0	400	200	2	2	0	0
452	300	10	0	0	0	0	250	10	0	0	0	0	0	0	0	0	0	0
451	150	10	10	11	0	273	100	10	5	6	0	360	80	50	2	2	0	96

Table 21. TIMES IN MODE BY GRID BY MODE FOR AIR TRAFFIC USING RUNWAY 24
(seconds)

	Air taxi						General aviation						Military					
Grid	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach	Idle	Taxi	Take-off	Land-ing	Climb-out	Approach
560	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
559	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
524	150	150	23	23	0	273	100	150	12	12	0	360	80	120	24	24	0	96
523	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0
522	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
493	300	230	10	10	40	0	250	230	6	6	40	0	0	0	0	0	5	0
492	0	0	0	0	0	0	0	0	0	0	0	0	400	100	0	0	0	0
452	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
451	300	0	0	0	185	0	250	0	0	0	260	0	0	0	0	0	25	0

Table 22 lists the air carrier aircraft and engines used at Lambert Field as compiled from the Official Airline Guide. The numbers of each type of engine were used to weight the emission factors for each to prepare a single, composite set of weighted emission factors for air carriers. The emission factors for each engine type and the weighted factors are presented in Table 23.

Table 22. AIRCRAFT AND ENGINE VOLUMES FOR LAMBERT FIELD, ST. LOUIS

Aircraft	Engine type							
	Number	JT3D	JT4A	JT8D	CJ805	JT9D	T56-A7	RRMK511
DC9	110			220				
727	76			228				
707	24	96						
CV5	25						50	
320	2		8					
880	2				8			
DC10	3					9		
737	5			10				
BAC111	5							10
TOTAL	252	96	8	458	8	9	50	10

Composite emission factors were also prepared for the other three aircraft categories. For air taxi the weighting factors are 100 T56-A7 engines and 20 RRMK511 engines. General aviation was given an equal distribution of 0-320, 0-360, and 0-200 engines. Military aircraft were half J79 and half J57 engines. The composite emission factors by pollutant and by mode are listed in Table 24. The SO_2 emission factors presented in this report are for an assumed 0.05 percent sulfur content fuel.[3]

Table 23. EMISSION FACTORS BY ENGINE TYPE AND MODE FOR AIR CARRIERS (kg/hr)

Mode	Pollutant	JT3D	JT4A	JT8D	CJ805	JT9D	T56-A7	RRMK511	Weighted factors
Idle	CO	49.4	28.5	15.2	28.9	46.3	6.94	27.3	20.66
	HC	44.7	29.4	3.71	12.4	12.4	2.93	30.0	10.77
	NO_x	0.649	1.23	1.32	0.712	2.75	0.98	0.385	1.19
	SO_2	0.396	0.631	0.435	0.454	0.788	0.249	0.300	0.42
	Particulate	0.20	0.54	0.16	0.59	1.0	0.73	0.077	0.23
Taxi	CO	49.4	28.5	15.2	28.9	46.3	6.94	27.3	20.66
	HC	44.7	29.4	3.7	12.4	12.4	2.93	30.0	10.77
	NO_x	0.649	1.23	1.32	0.712	2.75	0.98	0.385	1.19
	SO_2	0.396	0.631	0.435	0.454	0.788	0.249	0.300	0.42
	Particulate	0.2	0.54	0.16	0.59	1.0	0.73	0.077	0.23
Takeoff	CO	5.6	8.53	3.40	13.2	3.76	0.975	6.44	3.78
	HC	2.11	0.306	0.353	0.252	1.34	0.195	-----	0.61
	NO_x	67.1	107.0	89.8	50.3	327	10.40	69.4	82.92
	SO_2	4.915	7.051	3.971	4.518	7.735	1.943	3.459	3.97
	Particulate	3.7	95	1.7	6.8	1.7	1.7	7.3	2.25
Landing	CO	33.9	21.1	11.3	23.6	31.1	4.66	20.76	14.88
	HC	27.9	18.0	2.4	7.7	8.0	1.84	18.31	6.78
	NO_x	18.1	29.0	24.6	13.8	84.1	3.649	19.10	22.66
	SO_2	0.662	0.545	0.248	0.275	0.379	0.076	0.222	0.30
	Particulate	1.6	3.0	0.61	2.4	1.2	1.07	1.91	0.88
Climbout	CO	6.94	8.30	4.03	13.1	5.31	1.37	6.94	4.49
	HC	2.23	0.576	0.418	0.264	1.20	0.216	0.110	0.68
	NO_x	43.6	70.3	59.4	33.6	208	9.62	52.2	54.13
	SO_2	4.062	5.939	3.328	3.760	6.494	0.865	2.883	3.32
	Particulate	3.9	9.1	1.2	6.8	1.8	1.4	4.5	1.85
Approach	CO	18.0	11.9	8.26	19.4	14.8	1.66	17.7	9.63
	HC	3.56	1.74	0.794	1.10	1.36	0.235	1.91	1.21
	NO_x	9.89	16.3	14.0	8.07	24.5	3.53	13.8	12.66
	SO_2	1.877	2.724	1.546	1.713	2.361	0.478	1.384	1.54
	Particulate	3.6	2.7	0.68	2.3	1.0	1.4	0.68	1.23

Table 24. COMPOSITE EMISSION FACTORS FOR AIR TAXI, GENERAL AVIATION, AND MILITARY AIRCRAFT AT LAMBERT FIELD (kg/hr)

Mode	Pollutant	Air taxi	General aviation	Military
Idle	HC	7.442	0.428	24.0
	CO	10.333	4.779	36.0
	NO_x	0.881	0.006	1.5
	SO_2	0.258	0.005	0.509
	Particulate	0.621	0.0	10.0
Taxi	HC	7.442	0.428	24.0
	CO	10.333	4.779	36.0
	NO_x	0.881	0.006	1.5
	SO_2	0.258	0.005	0.509
	Particulate	0.621	0.0	10.0
Takeoff	HC	0.195	0.642	3.5
	CO	1.886	32.923	224.0
	NO_x	20.233	0.143	56.0
	SO_2	2.196	0.031	8.916
	Particulate	2.633	0.0	73.5
Landing	HC	4.585	0.451	24.0
	CO	7.343	12.764	36.0
	NO_x	6.224	0.044	1.5
	SO_2	0.100	0.012	0.509
	Particulate	1.210	0.0	10.0
Climbout	HC	0.198	0.488	1.5
	CO	2.298	28.393	6.0
	NO_x	16.717	0.157	42.5
	SO_2	1.201	0.027	3.898
	Particulate	1.917	0.0	48.0
Approach	HC	0.514	0.249	1.5
	CO	4.333	12.471	7.5
	NO_x	5.242	0.037	30.5
	SO_2	0.629	0.012	3.548
	Particulate	1.280	0.0	54.5

GROUND SERVICE VEHICLE OPERATIONS

The activity of ground service vehicles and the vehicles used depend on the type of aircraft being serviced. For Lambert Field, a composite time for servicing was computed for each of the various types of vehicles for the air carrier equipment mix. Table 25 presents a summary of ground service vehicle usage and times for the different types of aircraft.[2] The composite service time was computed using the aircraft volumes that were also used to compute composite emission factors. Table 26 lists the fuel consumption rates, while Table 27 gives the emission factors for each.[2] Emission factors for SO_2 can be computed from Table 27 and the sulfur content of the fuel. The hourly emissions from ground service vehicles are found by multiplying the times in Table 25, the consumption rates in Table 26, and the emission factors in Table 27 by half the hourly volume computed for aircraft activity.

FUEL HANDLING AND STORAGE

The Allied Aviation Fueling Company of St. Louis, Inc., is the major supplier of fuel at Lambert. The fuel is stored on a hill outside the airport boundary and is piped underground to the ramp area of the airline terminal. The majority of aircraft fueling is done directly from outlets on the ramp, although fueling trucks are used at a few locations.

The fuel storage tanks are equipped with vapor recovery systems and the cartridges are serviced regularly. Any fuel spillage during fueling is promptly washed away.

Approximately 12 million gallons of fuel are pumped per month.[6] The working loss of hydrocarbons varies with temperature, and Table 28 lists the 94 year average high, medium, and low temperatures for each month as compiled in the Climatic Atlas of the U. S.[7] The average low

Table 25. SERVICE TIMES OF AIRCRAFT GROUND SERVICE VEHICLES

Aircraft / Vehicle	Time in vehicle-minutes								Composite times
	DC-10	B-707	B-727	DC-9	B-737	C-880	F-227	C-580	
1. Tractor	148	66	66	48	85	40	55	50	56
2. Belt Loader	40	37	28	15	30	40	0	25	23
3. Container Loader	80	12	6	0	0	0	0	0	3
4. Cabin Service	25	12	12	0	15	0	0	0	5
5. Lavatory Truck	18	15	15	15	15	20	10	10	15
6. Water Truck	10	0	0	10	0	0	10	10	5
7. Food Truck	20	20	17	17	20	20	10	10	17
8. Fuel Truck	45	37	20	15	15	20	10	20	19
9. Tow Tractor	10	10	10	5	5	15	5	5	8
10. Conditioner	0	30	0	0	0	0	0	0	3
11. Airstart									
Transporting Engine	0	10	0	0	0	15	0	0	2
Diesel Power Unit	0	8	0	0	0	11	0	0	2

Table 25 (continued). SERVICE TIMES OF AIRCRAFT GROUND SERVICE VEHICLES

Aircraft / Vehicle	Time in vehicle-minutes								Composite times
	DC-10	B-707	B-727	DC-9	B-737	C-880	F-227	C-580	
12. Ground Power Unit									
Transporting Engine	0	9	0	0	0	35	0	0	4
Gasoline Power Unit	0	4	0	0	0	15	0	0	2
Diesel Power Unit	0	4	0	0	0	15	0	0	2
13. Transporter	0	10	3	0	0	0	0	0	2
14. Auxiliary Power Unit	Yes	No	Yes	Yes	Yes	No	No	No	30

Table 26. GROUND SERVICE VEHICLE FUEL CONSUMPTION RATES

Vehicle	Rate of fuel consumption (gal/hr)
1. Tractor	1.80
2. Belt Loader	0.70
3. Container Loader	1.75
4. Cabin Service	1.50[a]
5. Lavatory Truck	1.50[a]
[illegible] Water Truck	1.50[a]
7. Food Truck	2.00[a]
8. Fuel Truck	1.70[a]
9. Tow Tractor	2.35
10. Conditioner	1.75[a]
11. Airstart	
Transporting Engine	1.40
Diesel Power Unit	8.20
12. Ground Power Unit	
Transporting Engine	2.00
Gasoline Power Unit	5.00
Diesel Power Unit	7.10
13. Transporter	1.50
14. Auxiliary Power Unit	7.10

[a] Estimated values

Table 27. GROUND SERVICE VEHICLE EMISSION FACTORS

Vehicle	Pollutant emissions (grams/gal)			
	CO	HC	NO_x	Particulates
Gasoline Engines	999.0	223.2	57.0	1.8
Diesel Engines	147.6	29.5	154.4	11.4

Table 28. NINETY-FOUR YEAR AVERAGE HIGH, MEDIUM, AND LOW TEMPERATURES FOR ST. LOUIS
(°F)

Month	High	Medium	Low
January	40	32	23
February	44	35	25
March	53	43	32
April	66	55	44
May	75	64	53
June	85	74	63
July	89	78	67
August	87	77	66
September	81	70	58
October	70	59	47
November	59	49	35
December	43	35	27

temperature is used for the 8 p.m. to 8 a.m. period, the average medium is used for 8 a.m. to 1 p.m. and 3 p.m. to 8 p.m., and the average high is used for 1 p.m. to 3 p.m.

The hydrocarbon emission factors are calculated by using the method from the American Petroleum Institute publication API 2513.[8] Table 29 lists the working loss factors computed for each month for each time period.

The gallons of fuel pumped in any hour are computed by the same method used for aircraft volumes. Hence,

$$G_h = \frac{1}{2} \frac{(G_m)(D_i)(H_i)}{(OD_m)10^4} ,$$

where G_m is gallons/month (12 million) and the factor of 1/2 assumes an even distribution of landings and takeoffs. The mass emissions are then calculated by multiplying G_h by the emission factor appropriate to the hour of the day (Table 29), and then multiplying the result by the volume to mass factor of 2.8 kg/gal. These emissions are restricted to grids 492 (one third) and 523 (two thirds).

ENGINE TESTING AND MAINTENANCE

Engine testing and maintenance is done by McDonnell Douglas in association with their manufacturing facilities at Lambert. The details of their testing and maintenance are classified, since their production consists of military aircraft. Their production rate is "about" two aircraft per day, and hence this emission source will be excluded from the inventory

Table 29. WORKING LOSS FACTORS FOR THE THREE TIME PERIODS FOR EACH MONTH

Month	Working loss (gallons/1000 gallons throughput)		
	0800-1300 1500-2000	1300-1500	2000-0800
January	0.87	1.03	0.71
February	0.94	1.17	0.72
March	1.12	1.38	0.87
April	1.42	1.65	1.17
May	1.61	2.11	1.38
June	2.10	2.58	1.60
July	2.17	2.76	1.81
August	2.16	2.64	1.80
September	1.92	2.37	1.51
October	1.52	1.92	1.20
November	1.17	1.41	0.94
December	0.94	1.12	0.78

SECTION VI

SCOTT AIR FORCE BASE

Scott Air Force Base is an Air Medical and Airlift Wing of the Military Airlift Command. The air traffic is light; it averages approximately 40 flights per day.

AIRCRAFT FLIGHT ACTIVITY

The five months of data available from Scott [9] were not sufficient to determine the percent of traffic by month. Therefore, a monthly mean and standard deviation was calculated from the five months of data. This is used with the day of week and hour of the day percentages to find the hourly traffic. Since the flights are predominantly by military aircraft, the categories of jet and piston aircraft are used. Table 30 lists the monthly volumes and the five month means and standard deviations for the two categories.

Table 30. FIVE-MONTH AIR TRAFFIC VOLUMES, MEANS, AND STANDARD DEVIATIONS AT SCOTT AFB, 1973 - 1974

Month	Jet	Piston	Total
Sept.	1208	451	1659
Oct.	1088	470	1558
Nov.	788	400	1188
Dec.	461	281	742
Jan.	617	285	912
Mean	832	379	1212
Standard Deviation	313	87	397

Percentages by the day of the week are given in Table 31. Percentages by the hour of the day were obtained from percentages for 6-hour periods beginning at 0400. Thus, all hours within a 6-hour block are given the same percent of total daily traffic. These are shown in Table 32.

Table 31. PERCENT OF AIR TRAFFIC BY DAY OF WEEK AT SCOTT AFB

Day	Jet	Piston
Sunday	13.61	15.97
Monday	13.86	13.86
Tuesday	12.29	12.50
Wednesday	15.16	12.08
Thursday	14.58	15.93
Friday	15.75	14.11
Saturday	14.75	15.54

Scott Field lies in four grid elements as shown in Figure 5. There are only two runways at Scott, runways 13 and 31 (Figure 5). Hence the grid elements used for the different modes are easily defined, and these are implicit in Tables 33 and 34 which give the time in the various modes for each grid by runway and type of aircraft.

EMISSION FACTORS

Jet flights at Scott AFB are predominantly by C-9 and C-141 aircraft.[9] The C-9 has two JT8D engines, while the C-141 has four TF-33 engines.[10] The ratio of activity of the C-9 to C-141 is about 3.75 to 1.0, so the weighting by engine type is about 1.87 (JT8D) to 1.0 (TF-33). Composite emission factors based on these engines were calculated, and these are given in Table 35.

Table 32. PERCENT OF AIR TRAFFIC BY HOUR AT SCOTT AFB.

Hour	Jet	Piston
0000-0100	5.367	5.226
0100-0200	5.367	5.226
0200-0300	5.367	5.226
0300-0400	5.367	5.226
0400-0500	0.841	0.298
0500-0600	0.841	0.298
0600-0700	0.841	0.298
0700-0800	0.841	0.298
0800-0900	0.841	0.298
0900-1000	0.841	0.298
1000-1100	4.054	3.799
1100-1200	4.054	3.799
1200-1300	4.054	3.799
1300-1400	4.054	3.799
1400-1500	4.054	3.799
1500-1600	4.054	3.799
1600-1700	6.404	7.344
1700-1800	6.404	7.344
1800-1900	6.404	7.344
1900-2000	6.404	7.344
2000-2100	6.404	7.344
2100-2200	6.404	7.344
2200-2300	5.367	5.226
2300-2400	5.367	5.226

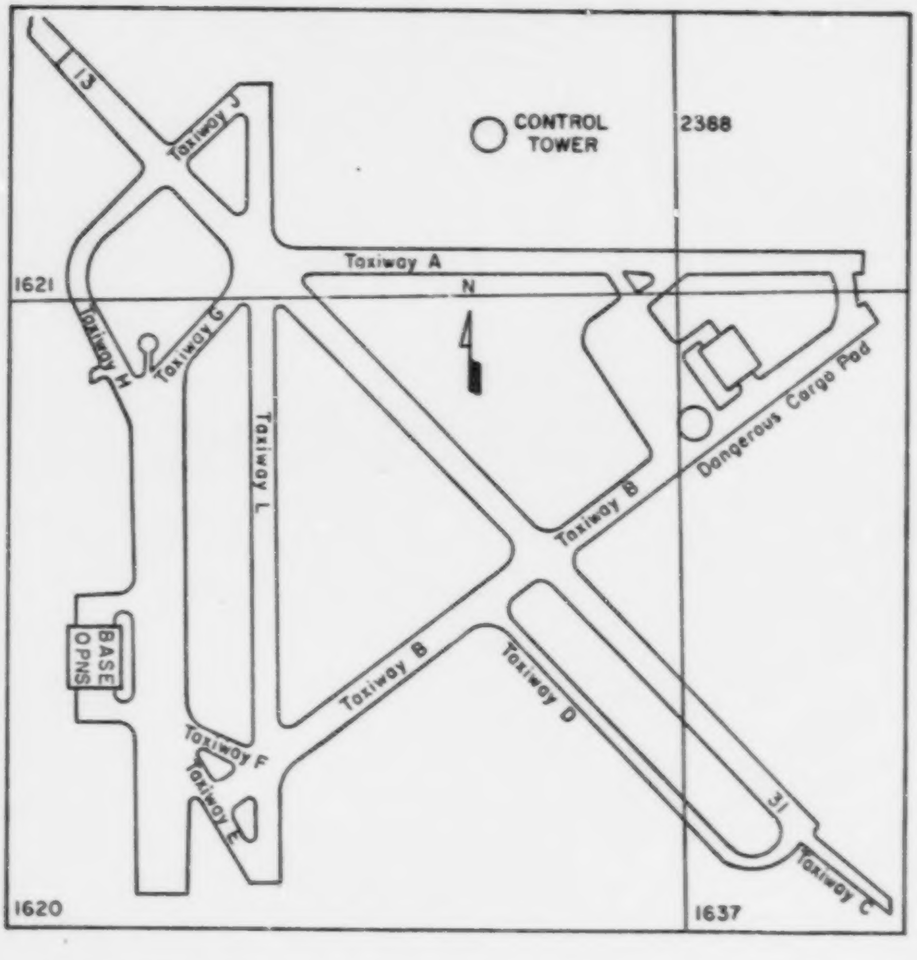
13
Taxiway J
CONTROL TOWER
2388
Taxiway A
1621
N
Taxiway H
Taxiway G
Taxiway L
Dangerous Cargo Pad
Taxiway B
BASE OPNS
Taxiway B
Taxiway D
Taxiway F
Taxiway E
31
Taxiway C
1620
1637

Figure 5. Runway layout and grid element overlay for Scott AFB

Table 33. TIME IN MODE BY GRID AND MODE FOR AIRCRAFT USING RUNWAY 13, SCOTT AFB
(seconds)

Mode	2388		1637		1621		1620	
	Jet	Piston	Jet	Piston	Jet	Piston	Jet	Piston
Idle	0	0	20	0	40	80	420	720
Taxi	0	0	40	50	50	50	510	600
Takeoff	0	0	0	0	20	16	22	20
Landing	0	0	0	0	15	16	20	20
Climbout	0	0	108	300	0	0	0	0
Approach	110	100	0	0	56	176	0	0

Table 34. TIME IN MODE BY GRID AND MODE FOR AIRCRAFT USING RUNWAY 31, SCOTT AFB
(seconds)

Mode	2388		1637		1621		1620	
	Jet	Piston	Jet	Piston	Jet	Piston	Jet	Piston
Idle	0	0	40	80	20	0	420	720
Taxi	0	0	20	50	20	50	800	700
Takeoff	0	0	10	16	0	20	32	0
Landing	0	0	5	10	0	26	30	0
Climbout	70	200	0	0	30	100	8	0
Approach	0	0	166	276	0	0	0	0

Table 35. EMISSION FACTORS FOR SCOTT AFB
(kg/hr)

Mode	Pollutant	Jet	Piston
Idle	CO	31.70	59.00
	HC	22.51	10.30
	NO_x	1.17	0.08
	SO_2	0.470	0.072
	Particulate	1.60	NA
Taxi	CO	31.70	64.50
	HC	22.51	13.20
	NO_x	1.17	0.06
	SO_2	0.470	0.073
	Particulate	1.60	NA
Takeoff	CO	3.18	417.70
	HC	0.60	9.23
	NO_x	77.09	2.15
	SO_2	3.949	0.403
	Particulate	20.16	NA
Landing	CO	21.56	160.62
	HC	15.38	8.96
	NO_x	21.29	0.67
	SO_2	0.695	0.164
	Particulate	7.26	NA
Climbout	CO	4.07	305.80
	HC	0.71	5.43
	NO_x	50.91	1.85
	SO_2	3.388	0.309
	Particulate	18.19	NA
Approach	CO	10.95	156.10
	HC	10.96	3.50
	NO_x	12.96	0.64
	SO_2	1.600	0.152
	Particulate	9.15	NA

Piston aircraft flights are largely by T-29, C-118, and C-131 aircraft, all of which use Pratt Whitney R-2800 engines. Emission factors[11] for piston aircraft flights are also listed in Table 35.

GROUND SERVICE VEHICLE OPERATIONS

There are eight petroleum, oil, and lubricants trucks, or POL trucks used to service aircraft at Scott Field. These run an average of 3 hours 25 minutes each per day,[9] or a total of 27 hours 20 minutes in grid element number 1620.

In addition to the POL trucks, the fleet service vehicles listed in Table 36 are used. Their combined use accounts for approximately 15 gallons of fuel per day.[9] Emission factors for these vehicles are given in the previous Table 27. The hourly emissions are computed by distributing the daily emissions according to the average hourly percent of daily activity for piston and jet aircraft.

Table 36. GROUND SERVICE VEHICLES USED AT SCOTT AFB

Service vehicle	Number
Fork lift	2
Water truck	1
Multi-stop	2
High lift	1
Lavatory truck	2
Warehouse tug	2
Step van	2

Emissions from the POL trucks are found using the fuel consumption rate for fuel trucks given in Table 26 (1.70 gallons/hour) and the emission factors from Table 27. These total emissions are also distributed by the hourly percent of daily activity to find the emissions for a particular hour.

FUEL HANDLING AND STORAGE

The volume of fuel stored at Scott AFB is classified. The average use is 724,000 gallons of jet fuel and 82,000 gallons of avgas per month. Hourly volumes of fuel pumped can be calculated using the day of week and hour of day percentages used to find activity. The emissions are then calculated using the factors given in Table 29 for jet fuel and a factor of 5 kg/1000 gallons pumped for avgas.

ENGINE TESTING AND MAINTENANCE

Engine testing and maintenance activity does not follow a prescribed schedule and hence cannot be accurately accounted for on an hourly basis. Emissions could be computed as an average value for each hour, but the number of engine runups is so small (about 14 per week) that the emissions would be lost on an hourly basis.

SECTION VII

CIVILIAN AIRPORTS

INTRODUCTION

Civilian airports can be divided into those with control towers and those without. This division also applies to the degree of data availability, and to the volume and type of traffic. Two civilian airports in the St. Louis AQCR, Spirit of St. Louis and Civic Memorial, have control towers; the remainder do not.

FLIGHT ACTIVITY

More extensive data are available for Civic Memorial Airport from the FAA control tower. These data have been reduced in the same manner as those for Lambert Field. Table 37 gives the monthly percentages of annual traffic, Table 38 gives the percentages by the day of the week, and the percentages by the hour of the day are listed in Table 39. These data are used to compute hourly traffic by the same method described for Lambert Field.

Uncontrolled airports do not record air traffic volumes. However, FAA Forms 5010-1 list estimated annual volumes which can be used with the distribution of traffic found at Civic Memorial. Table 40 presents the annual volumes from FAA Forms 5010-1. Two exceptions are Civic Memorial and Spirit of St. Louis for which the volumes were obtained from control tower records.

Table 37. PERCENT OF AIR TRAFFIC BY MONTH AT CIVIC MEMORIAL AIRPORT

Month	Monthly percent
January	7.86
February	7.95
March	6.98
April	9.26
May	9.48
June	8.88
July	8.44
August	9.90
September	7.78
October	9.48
November	8.49
December	5.50

Table 38. PERCENT OF AIR TRAFFIC BY DAY OF WEEK AT CIVIC MEMORIAL AIRPORT

Day	Day percent
Sunday	17.47
Monday	11.14
Tuesday	12.54
Wednesday	13.30
Thursday	12.76
Friday	14.10
Saturday	18.69

Table 39. PERCENT OF AIR TRAFFIC BY HOUR OF THE DAY AT CIVIC MEMORIAL AIRPORT

Hour	Hourly percent
0700 - 0800	1.15
0800 - 0900	4.63
0900 - 1000	7.20
1000 - 1100	7.08
1100 - 1200	8.82
1200 - 1300	9.51
1300 - 1400	10.51
1400 - 1500	10.83
1500 - 1600	12.45
1600 - 1700	12.91
1700 - 1800	6.17
1800 - 1900	3.19
1900 - 2000	2.23
2000 - 2100	2.40
2100 - 2200	0.56
2200 - 2300	0.34

Table 40. ANNUAL AIR TRAFFIC VOLUMES AT CIVILIAN AIRPORTS IN THE ST. LOUIS AQCR

Airport	Annual volume
St. Clair	14,400
Wentzville	27,000
Arrowhead	60,500
Creve Coeur	63,100
St. Charles	63,000
St. Charles Smartt	27,000
Weiss	130,000
Festus	15,000
Gelhardt	14,183
Sparta	8,012
Highland	28,000
Greenville	38,734
Bi-State Parks	192,030
Civic Memorial	156,607
Spirit of St. Louis	114,426

SPATIAL DETAIL

Five of the general aviation airports lie in more than one grid element. These are Civic Memorial, Spirit of St. Louis, Bi-State Parks, St. Clair, and Creve Coeur Airports. The remaining ten are contained in one grid. Figures 6 through 10 show the layout of the multi-grid airports. The grids and the key operating modes for each grid for each active runway are listed in Tables 41 through 45.

The airports which lie in only one grid element are listed, along with the grid numbers and sizes, in Table 46. Figures 11 through 20 depict the layout of these remaining airports.

EMISSIONS FROM FLIGHT ACTIVITY

The emission factors for the civilian airports are those for general aviation listed in Table 24 for a mix of general aviation aircraft types. The average times in mode are given in Table 47. When an airport lies in more than one grid, the time for each mode is distributed equally among the grids identified for the mode (Tables 41 through 45). The emissions are computed by the same multiplication of volume, emission factors, and times in mode as described for Lambert Field.

GROUND SERVICE VEHICLES

Ground service vehicles at civilian airports are limited to fueling trucks, and even these are absent at all but the large civilian airports. Most of these airports provide fueling as at a gas station; airplanes are taxied to the gas pump for filling.

The fueling truck operation is erratic, depending on the amount of traffic, and it is not possible to pin down the actual operating characteristics.

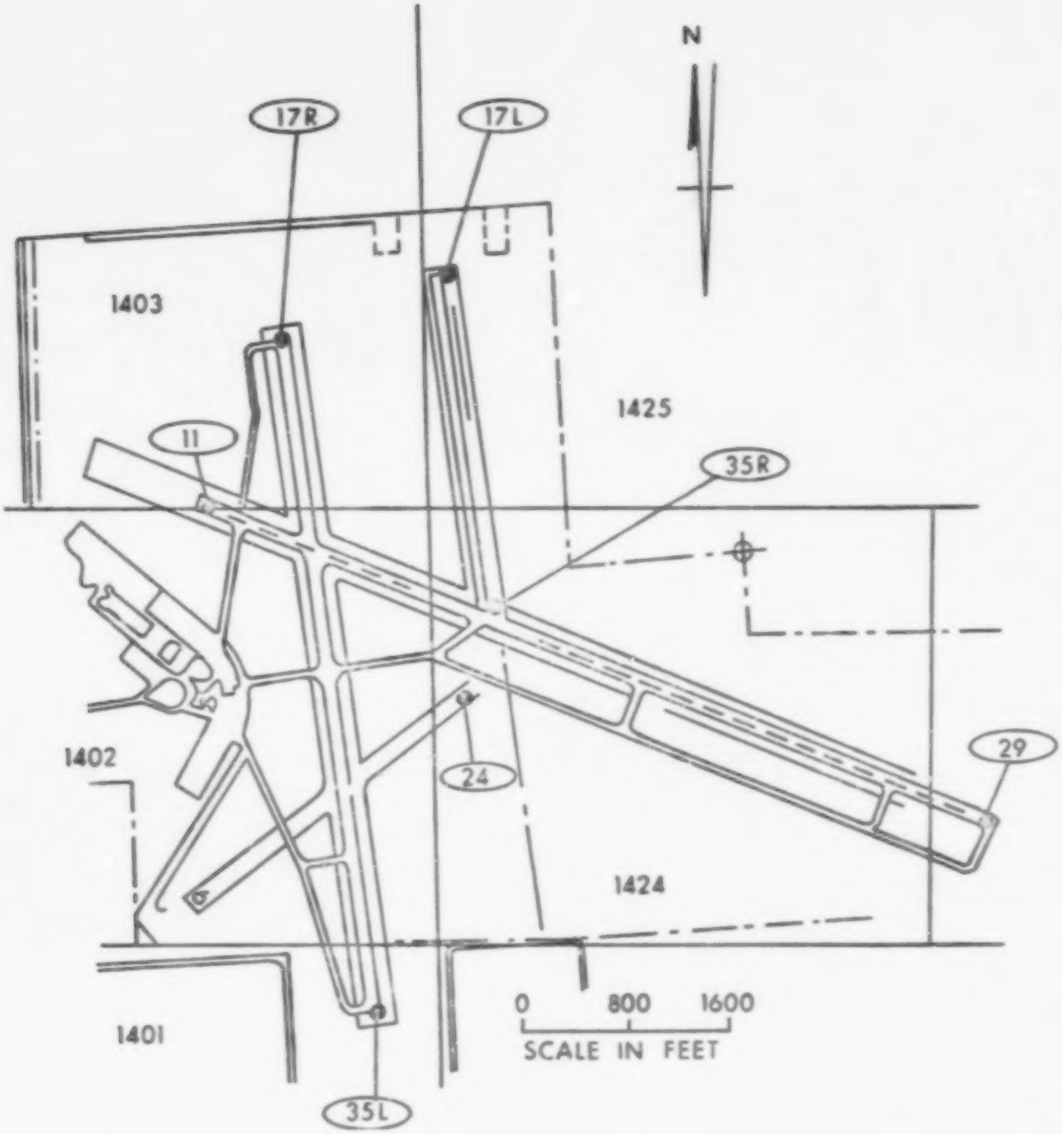
N
17R
17L
1403
1425
11
35R
1402
24
29
1424
1401
0
800
1600
SCALE IN FEET
35L

Figure 6. Diagram of Civic Memorial Airport showing grid element overlay

Table 41. OPERATING MODES FOR EACH GRID BY ACTIVE RUNWAY AT CIVIC MEMORIAL AIRPORT

Runway	Grid	X-coord	Y-coord	Size	Idle	Taxi	Takeoff	Climbout	Approach	Landing	Taxi
11	1402	4308	755	1		x	x			x	x
	1403	4309	755	1		x	x			x	
	1424	4308	756	1			x			x	x
	1444	4309	757	2			x			x	x
29	1402					x	x			x	x
	1403						x			x	
	1424					x	x			x	x
	1444					x	x			x	
17	1401	4307	755	1			x			x	x
	1402					x	x			x	x
	1403					x	x			x	
35	1401					x	x			x	
	1402					x	x			x	x
	1403						x			x	x

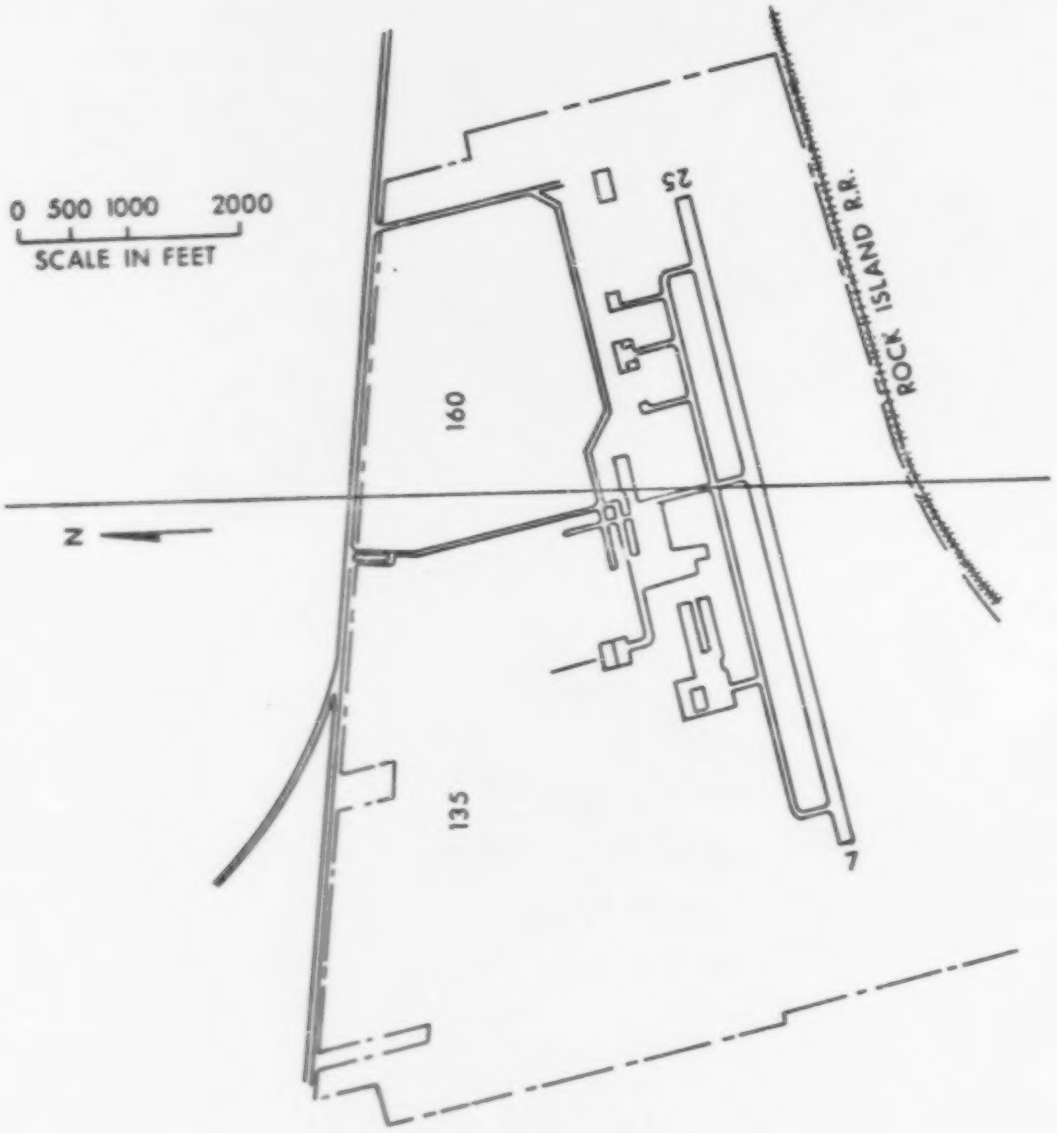
0 500 1000 2000
SCALE IN FEET
25
ROCK ISLAND R.R.
160
N
135
7

Figure 7. Diagram of Spirit of St. Louis Airport showing grid element overlay

Table 42. OPERATING MODES FOR EACH GRID BY ACTIVE RUNWAY AT SPIRIT OF ST. LOUIS AIRPORT

Runway	Grid	X-coord	Y-coord	Size	Idle	Taxi	Takeoff	Climbout	Approach	Landing	Taxi
8	135	4280	700	5		X	X			X	X
	160	4280	705	5		X	X			X	X
26	135					X	X			X	X
	160					X	X			X	X

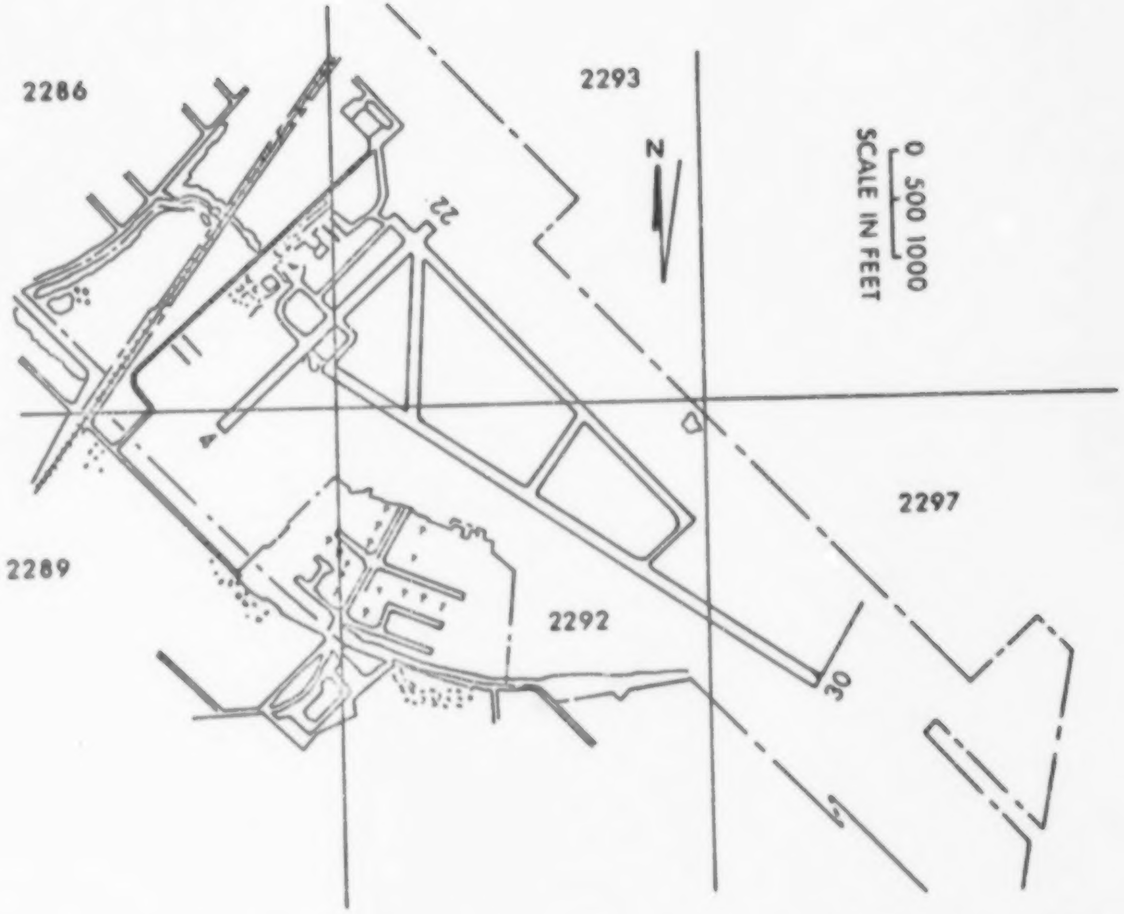
2286
2293
2289
2292
2297
22
30
N
0 500 1000
SCALE IN FEET

Figure 8. Diagram of Bi-State Parks Airport showing grid element overlay

Table 43. KEY OPERATING MODES FOR EACH GRID FOR EACH RUNWAY AT BI-STATE PARKS AIRPORT

Runway	Grid	Size	Idle	Taxi	Takeoff	Landing	Taxi
4	2286	2	X	X	X	X	X
	2293	1			X	X	X
	2289	1	X	X	X	X	
22	2286	2			X	X	X
	2293	1	X	X	X	X	
12	2286	2	X	X			
	2292	1			X	X	X
	2293	1			X	X	
	2297	1			X	X	
30	2292	1			X	X	
	2293	1	X	X	X	X	X
	2297	1		X	X	X	

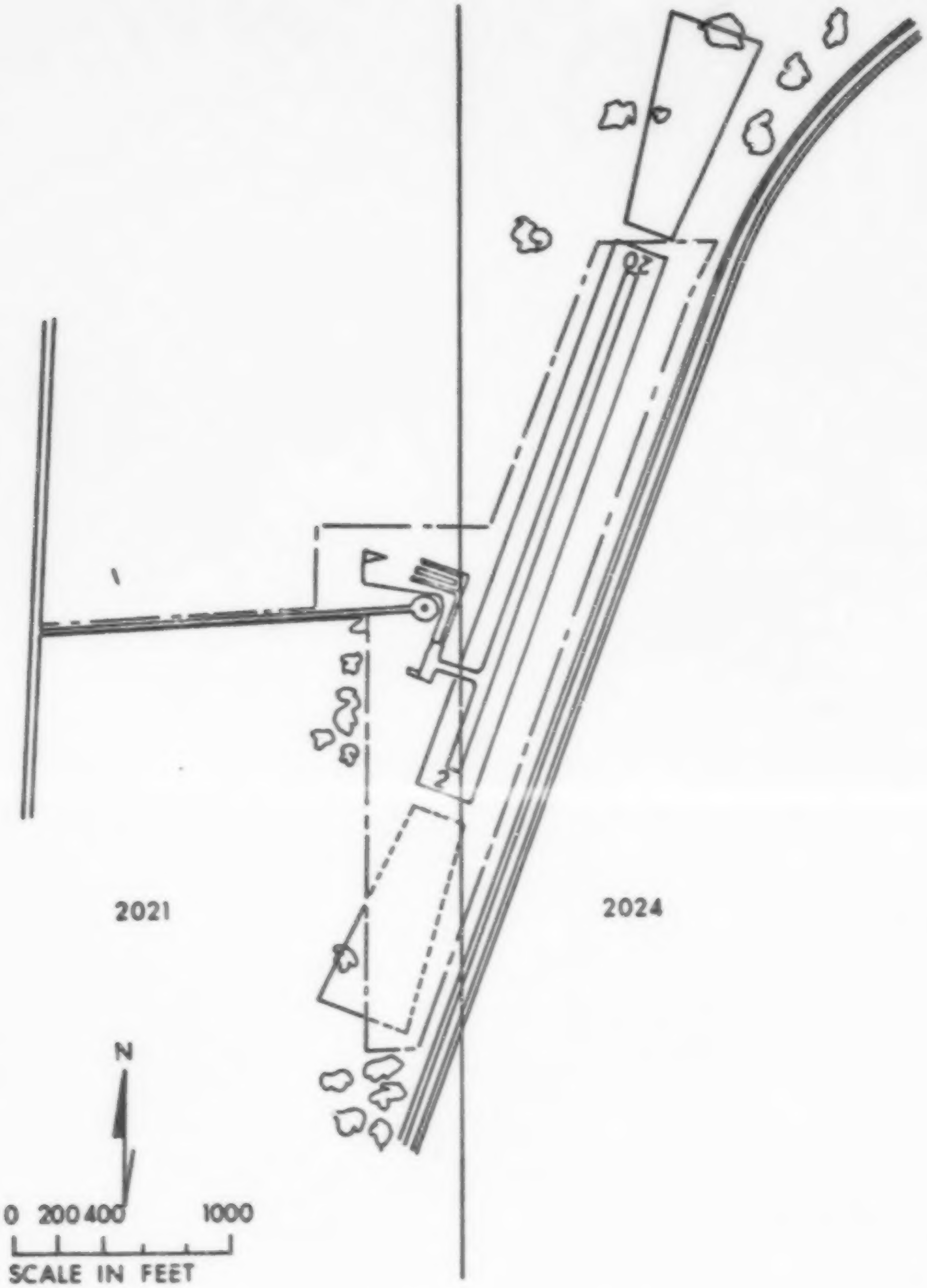
2021
2024
02
20
N
0 200 400 1000
SCALE IN FEET

Figure 9. Diagram of St. Clair Airport showing grid element overlay

Table 44. KEY OPERATING MODES FOR EACH GRID FOR EACH RUNWAY AT ST. CLAIR AIRPORT

Runway	Grid	Size	Idle	Taxi	Takeoff	Landing	Taxi
2	2021	2	X	X			X
	2024	3		X	X	X	X
20	2021	2	X	X			X
	2024	3		X	X	X	X

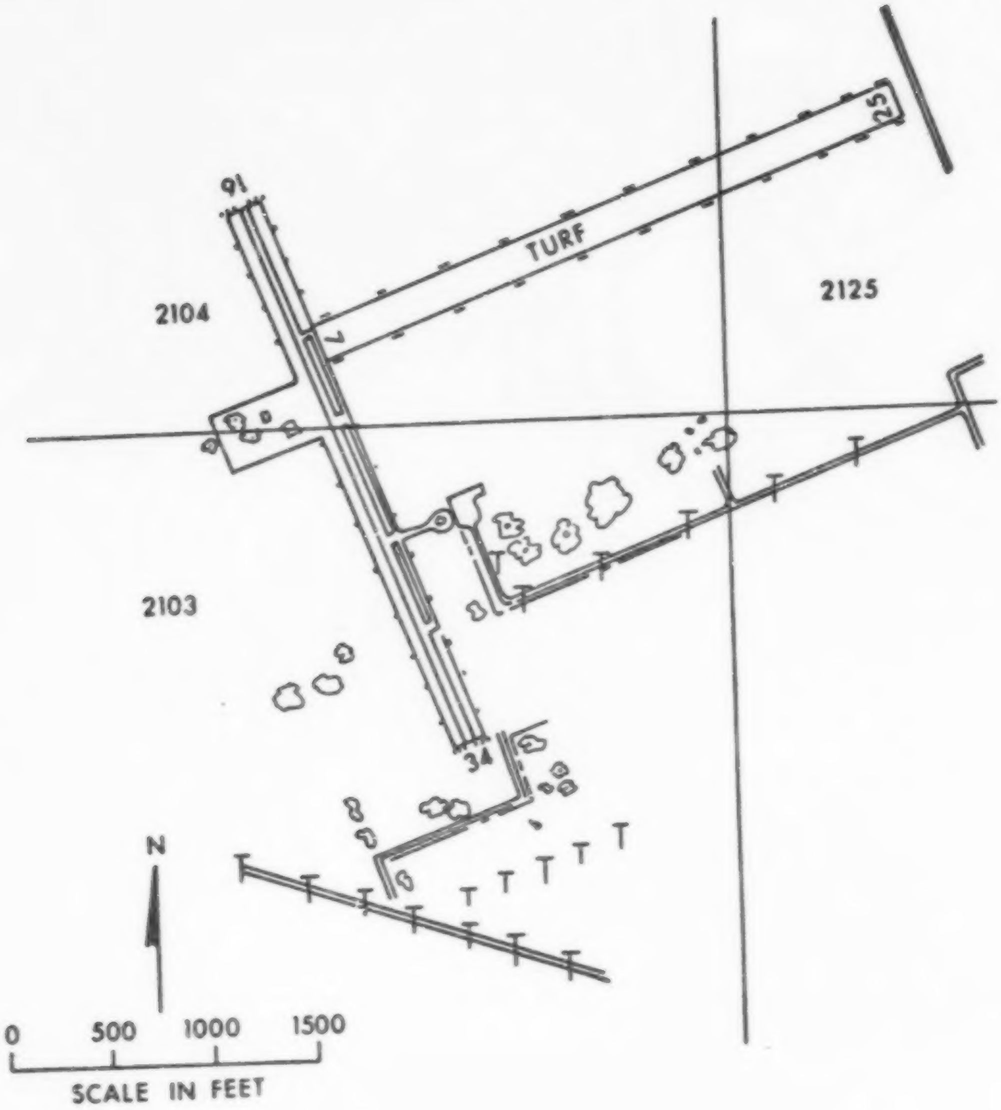
91
TURF
7
25
2104
2125
2103
34
N
0
500
1000
1500
SCALE IN FEET

Figure 10. Diagram of Creve Coeur Airport showing grid element overlay

Table 45. KEY OPERATING MODES FOR EACH GRID FOR EACH RUNWAY AT CREVE COEUR AIRPORT

Runway	Grid	Size	Idle	Taxi	Takeoff	Landing	Taxi
16	2103	2	X	X	X	X	X
	2104	2		X	X	X	
34	2103	2	X	X	X	X	X
	2104	2			X	X	X
7	2103	2	X	X			X
	2104	2		X	X	X	X
	2125	2			X	X	X
25	2103	2	X	X			X
	2104	2		X	X	X	X
	2105	2		X	X	X	

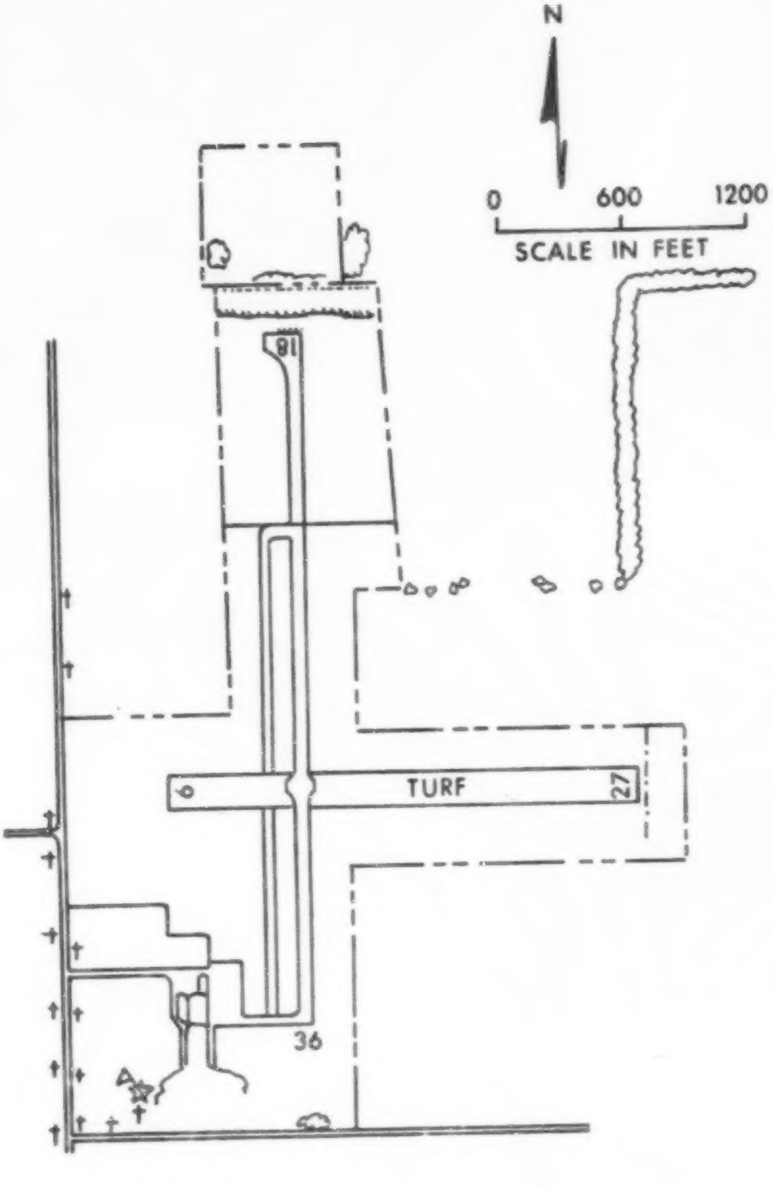
N
0
600
1200
SCALE IN FEET
18
9
TURF
27
36

Figure 11. Diagram of Sparta Airport - grid element 1633

Table 46. GENERAL AVIATION AIRPORTS CONTAINED IN ONE GRID, ST. LOUIS AQCR

Airport	Grid number	Grid size (km)
Wentzville	76	10.0
Arrowhead	2102	2.0
St. Charles	241	5.0
St. Charles Smartt	242	10.0
Weiss	2161	4.0
Festus	467	2.0
Gebhardt	883	2.0
Sparta	1633	10.0
Highland	1709	10.0
Greenville	1815	10.0

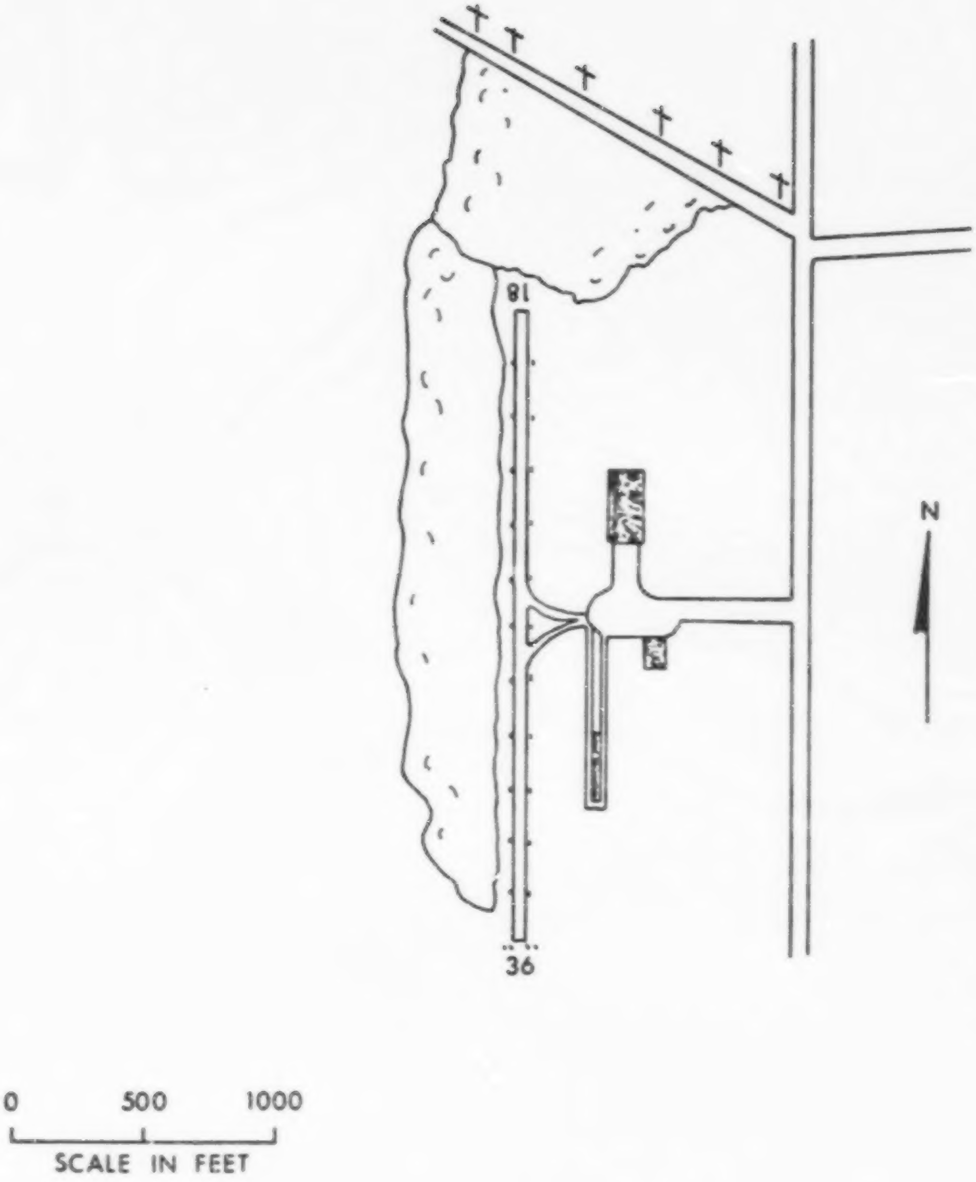
18
36
N
0
500
1000
SCALE IN FEET

Figure 12. Diagram of Wentzville Airport - grid element 76

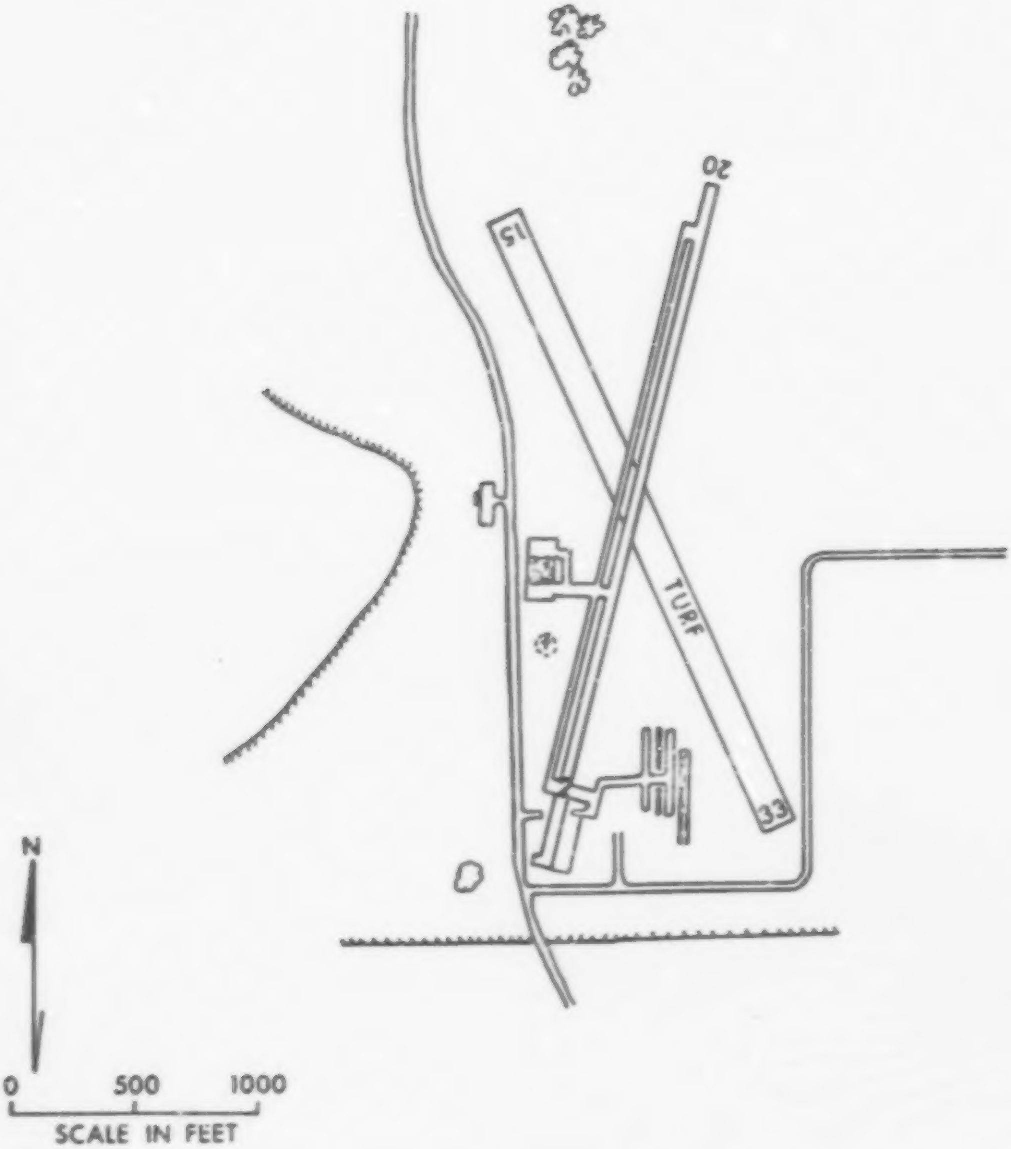
20
15
TURF
33
N
0
500
1000
SCALE IN FEET

Figure 13. Diagram of Arrowhead Airport - grid element 2102

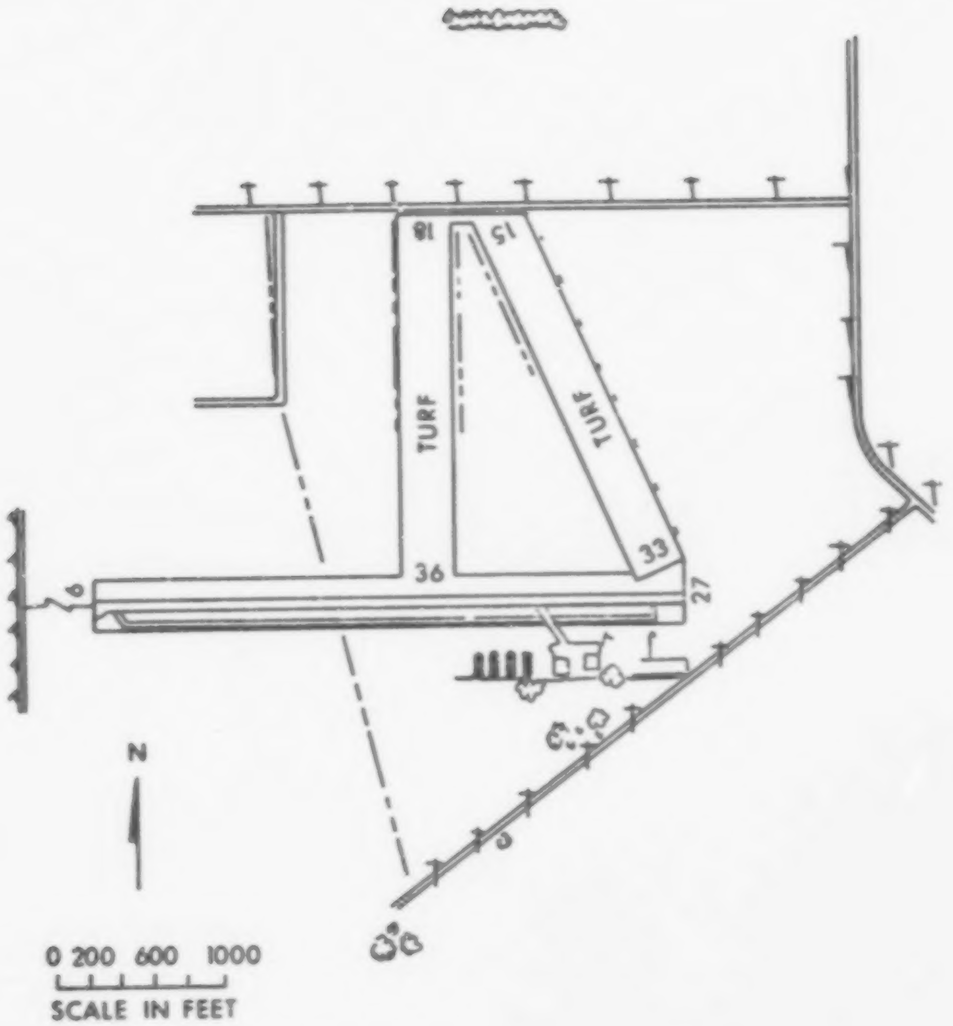
18
15
TURF
TURF
33
36
27
9
N
0 200 600 1000
SCALE IN FEET

Figure 14. Diagram of St. Charles Airport - grid element 241

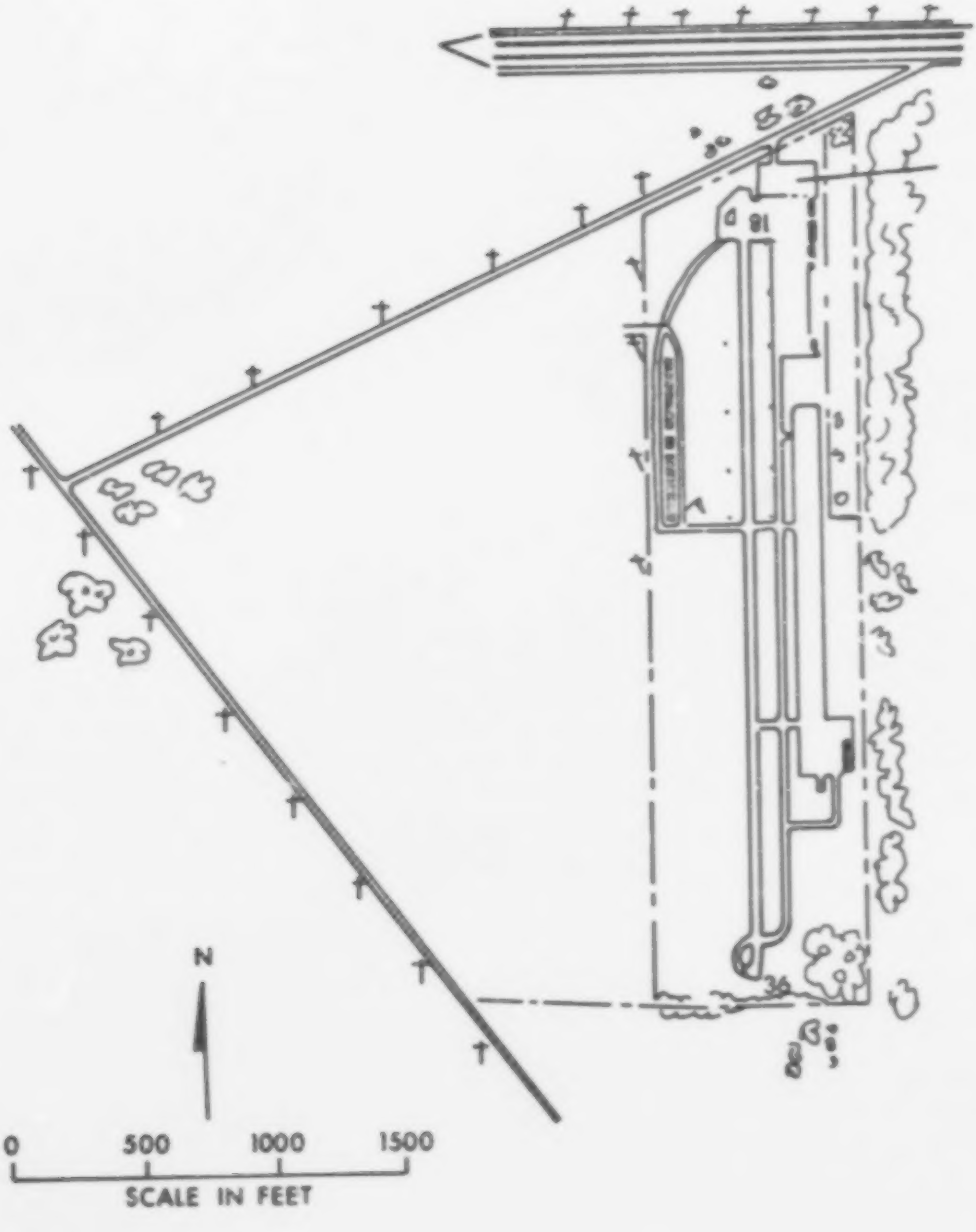
18
36
N
0
500
1000
1500
SCALE IN FEET

Figure 15. Diagram of Weiss Airport - grid element 2161

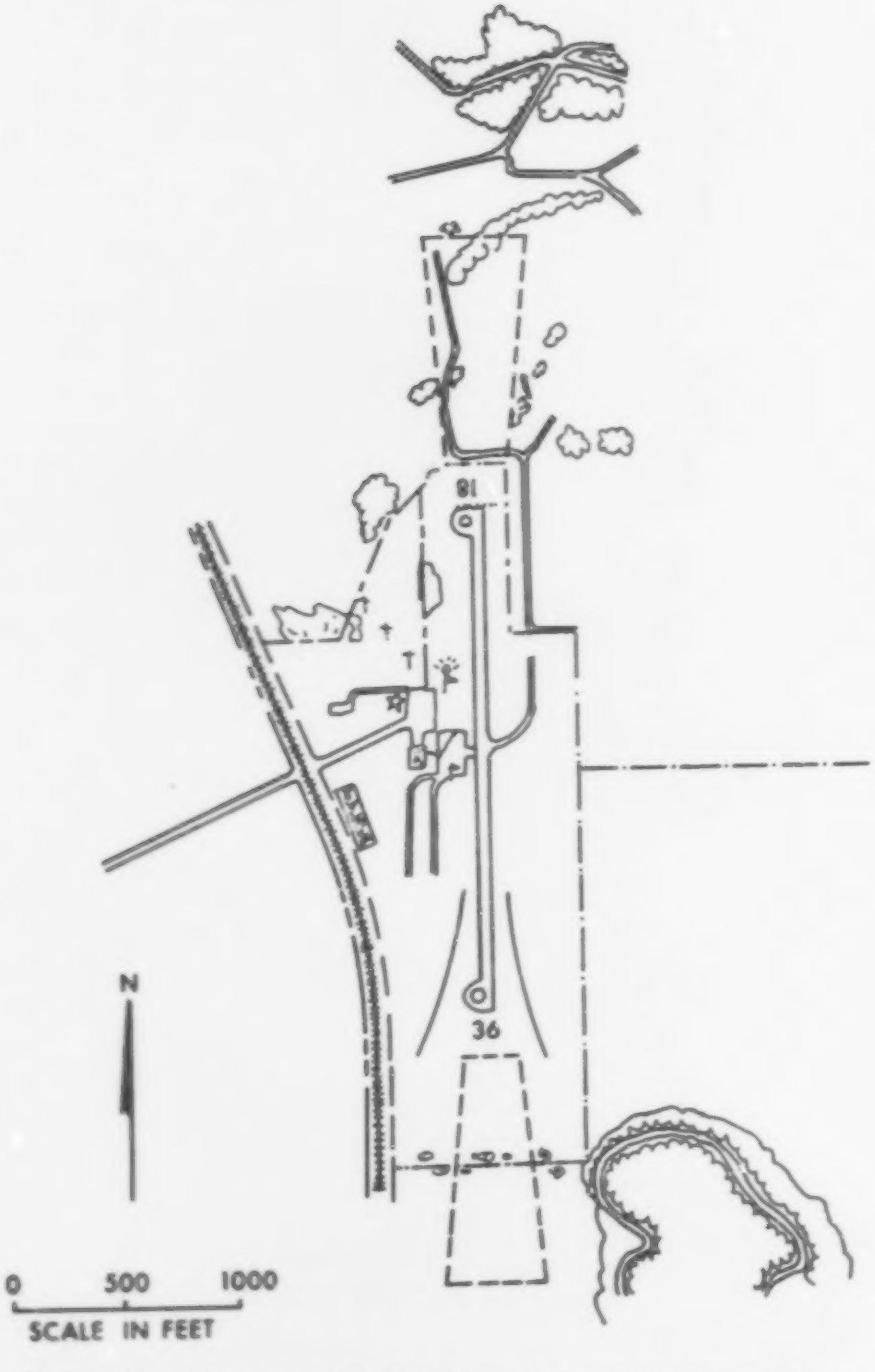
81
36
N
0
500
1000
SCALE IN FEET

Figure 16. Diagram of Festus Airport - grid element 467

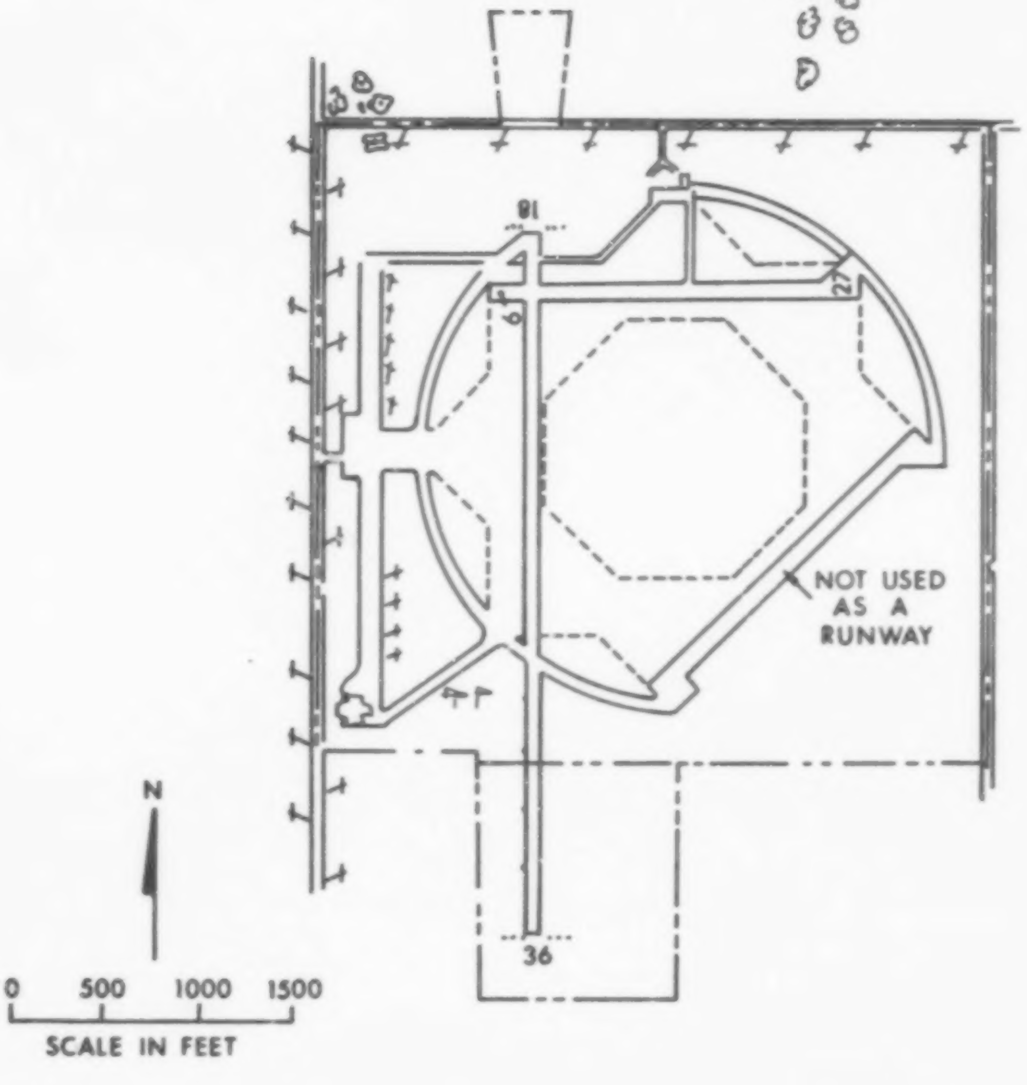
81
9
27
NOT USED AS A RUNWAY
36
N
0
500
1000
1500
SCALE IN FEET

Figure 17. Diagram of St. Charles Smartt Airport - grid element 242

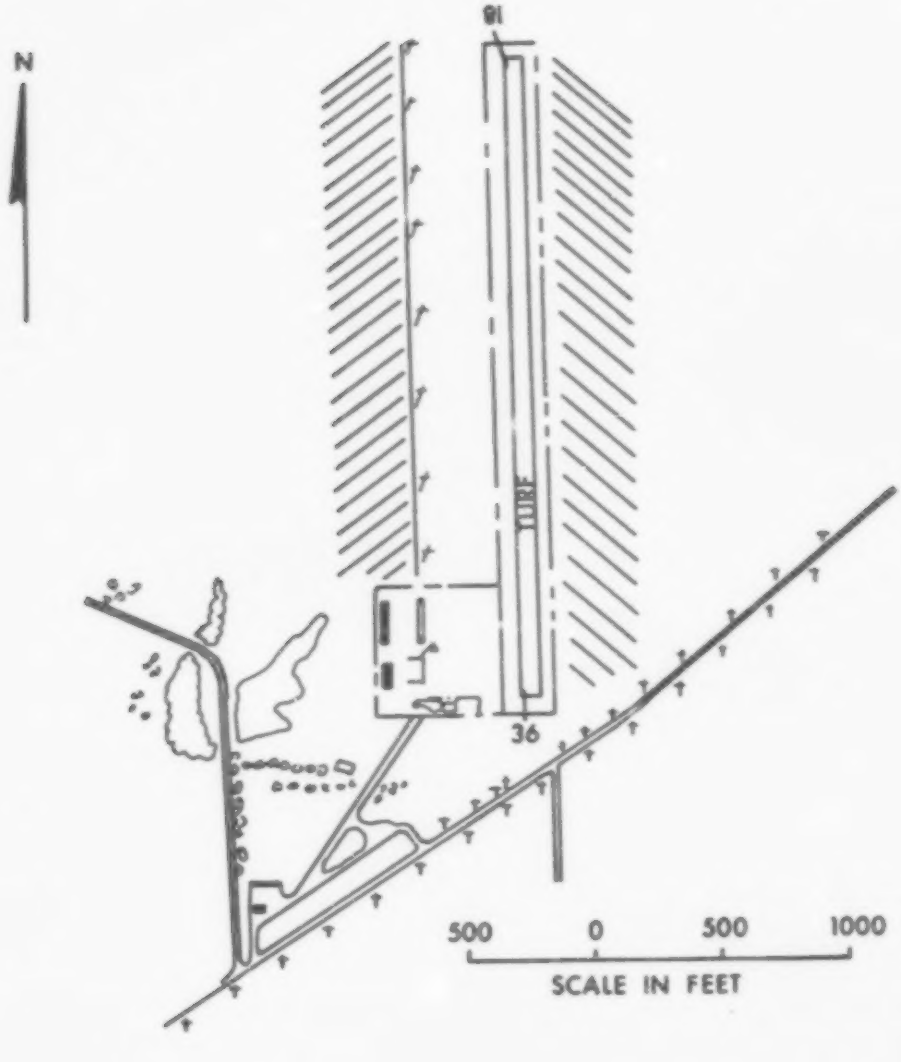
N
18
TURF
36
500
0
500
1000
SCALE IN FEET

Figure 18. Diagram of Highland Airport - grid element 1709

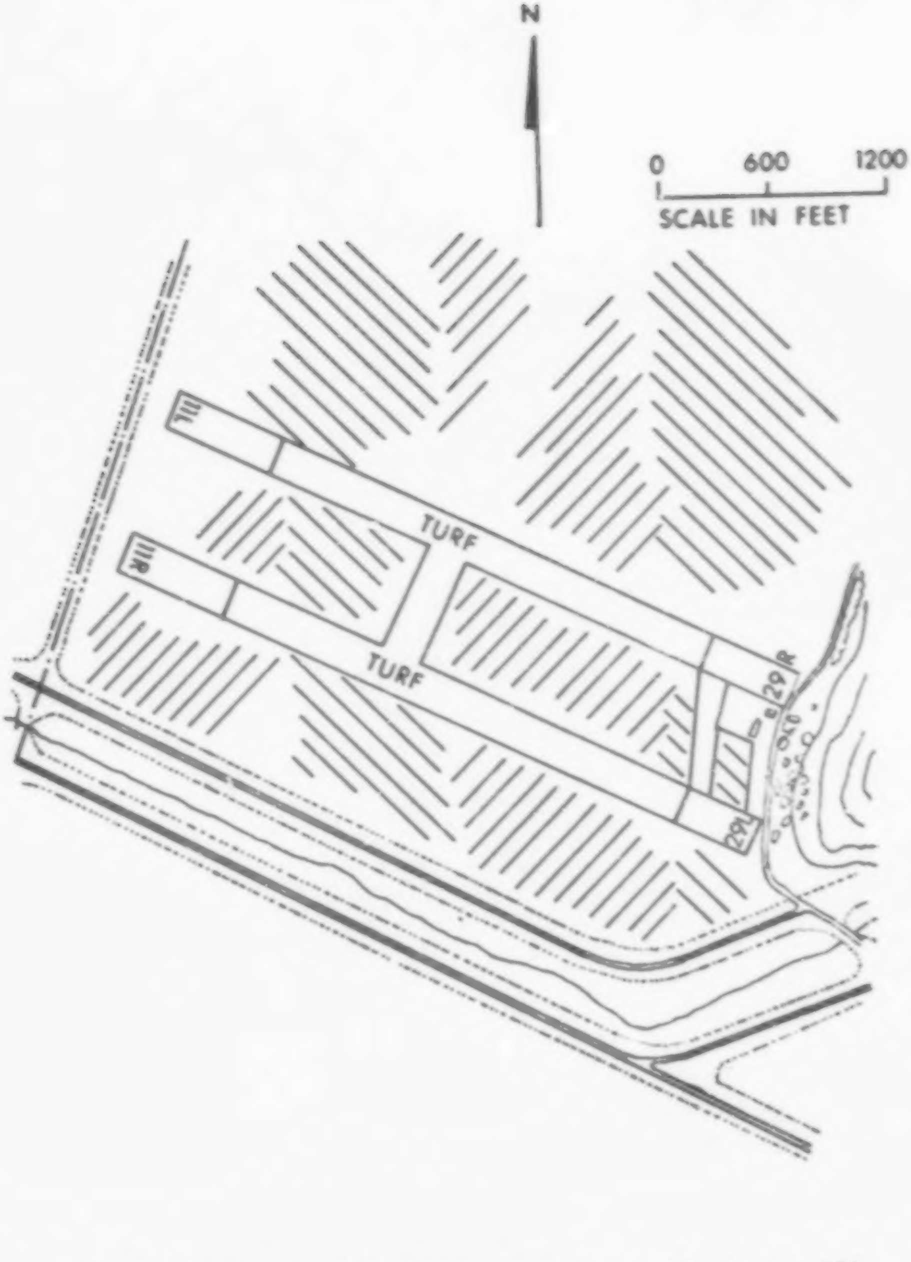
N
0
600
1200
SCALE IN FEET
TURF
TURF
11L
11R
29R
29L

Figure 19. Diagram of Gebhardt Airport - grid element 883

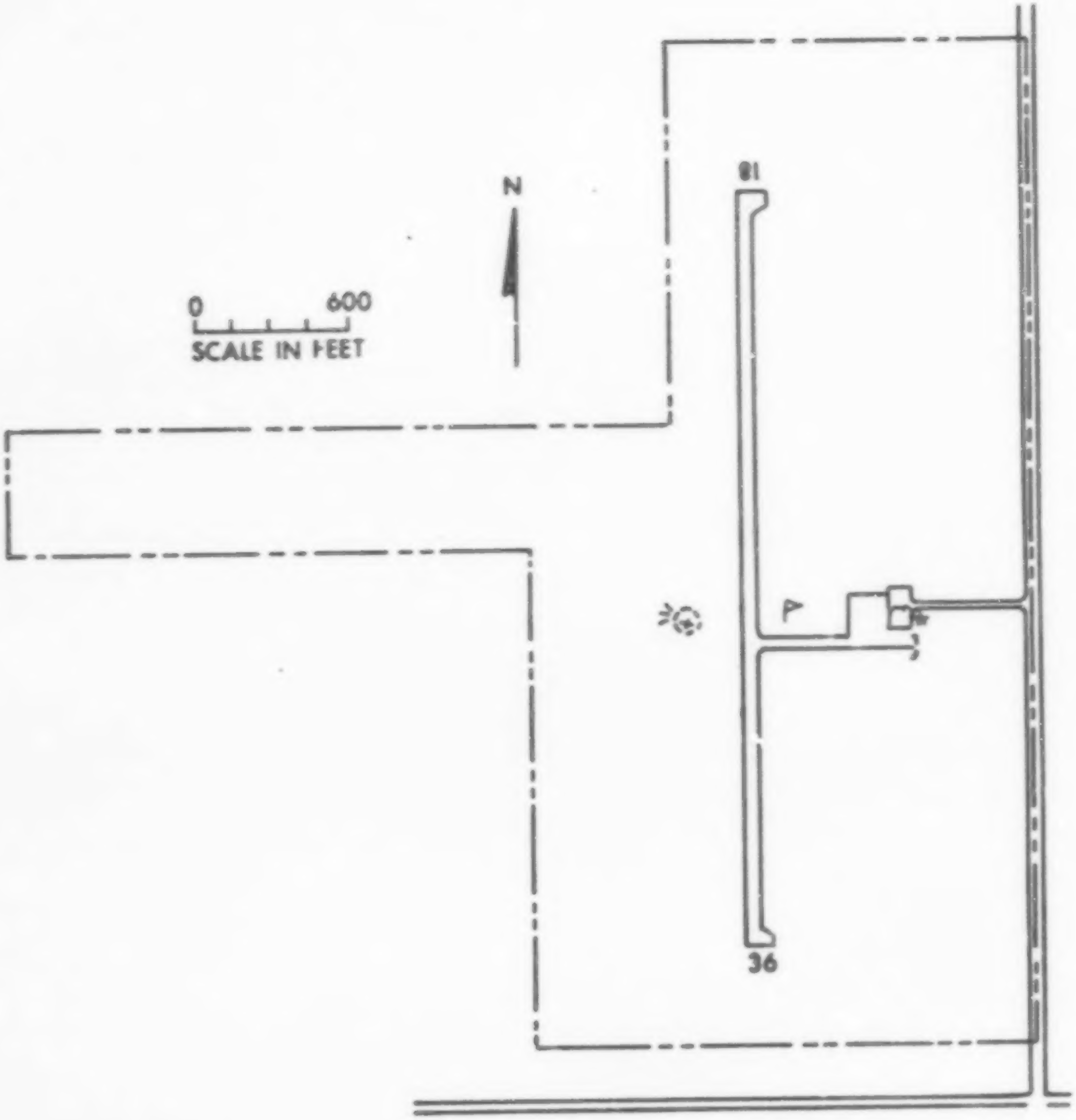
N
0
600
SCALE IN FEET
18
36

Figure 20. Diagram of Greenville Airport - grid element 1815

Table 47. TIMES IN MODE FOR GENERAL AVIATION AIRCRAFT AT CIVILIAN AIRPORTS

Mode	Time (minutes)
Idle	8.0
Taxi	8.0
Takeoff	0.3
Landing	0.3
Climbout	4.98
Approach	6.00

Table 48. ANNUAL VOLUMES OF FUEL SALES AT THE GENERAL AVIATION AIRPORTS

Airport	Annual fuel sales (1000 gallons)
Sparta	36
Greenville	15
Gebhardt	15
Highland	26
Bi-State Parks	350
Civic Memorial	350
Festus	42
Weiss	48
Creve Coeur	26
St. Charles	48
St. Charles Smartt	20
St. Clair	48
Arrowhead	48
Wentzville	15
Spirit of St. Louis	200

The emissions from one or two fueling trucks are negligible compared to emissions from automobile traffic, and hence ground service vehicle emissions (where they exist) will be excluded from the methodology for civilian airports.

FUEL STORAGE AND HANDLING

Fuel storage and handling losses are calculated as at Lambert and Scott. The working loss factor is 5 kg/1000 gallons. The general aviation airports were surveyed to determine their fuel sales. Table 48 shows the annual gallons of fuel pumped at each airport. These annual figures are converted to hourly volumes by applying the aircraft volume distributions of Tables 37, 38, and 39 as described previously for Lambert Field.

ENGINE TESTING AND MAINTENANCE

Engine testing and maintenance at the small airports is limited and sometimes non-existent. Predicting the occurrence or frequency of this emission source with any accuracy is unreasonable on an hourly basis. Because of this, and because this source is such a small contributor to emissions at these airports, emissions from engine testing and maintenance will not be considered.

SECTION VIII

METHODOLOGY SUMMARY

This section presents a "step-by-step" methodology for computing emissions at the airports in the St. Louis AQCR. It is based on the results of data collection from the individual airports. It is also based on an assessment of the amount of detail which can be extracted from available data and on the extent to which additional data can be reasonably and reliably collected in the field. The basic method by which emissions are estimated is to construct matrices and vectors of the applicable data and then to add and multiply these matrices and vectors so that the result is hourly emissions for each of the grid elements involved.

LAMBERT FIELD

Emissions From Aircraft Flight Operations

Step 1. Identify the month, day of the week, and hour of the day for which emissions are to be estimated.

Step 2. Determine the active runway from the wind direction and/or aircraft category.

Step 3. For the time identified (Step 1), determine the activity factors for the different aircraft types:

M_i = percent of annual volume occurring during the month (aircraft category i),

D_i = percent of monthly volume occurring on the given day of the week (aircraft category i),

H_i = percent of daily volume occurring during the hour of interest (aircraft category i).

Step 4. For the active runway determined in Step 2, locate the k grid elements through which aircraft pass.

Step 5. Determine the percent of activity due to takeoffs and the percent due to landings for the different aircraft types for the hour:

to_i = percent taking off (aircraft category i),

l_i = percent landing (aircraft category i).

Step 6. Compute the takeoff and landing volumes for the hour for each category as follows:

$$VTO_i = \frac{A \cdot M_i \cdot D_i \cdot H_i \cdot to_i}{(OD_M)(10^8)} ,$$

where:

VTO_i = number of takeoffs for aircraft category i

A = annual air traffic volume

OD_M = average occurrence of the day of the week during the month

= 4.43 for 31-day months

= 4.29 for 30-day months

= 4.00 for February (4.14 in a leap year)

10^8 = factor to convert percentages to decimals.

Likewise,

$$VL_i = \frac{A \cdot M_i \cdot D_i \cdot H_i \cdot l_i}{(OD_M)(10^8)}$$

Step 7. For the different aircraft categories, activity volumes, and grid elements identified above, determine the j engine operating modes for each grid element.

Step 8. Determine the time-in-mode for each aircraft category for each mode in each grid.

T_{jik} = time-in-mode j for aircraft category i in grid k.

Step 9. Identify the emission rates of the l pollutants, EF_{ilj}, of the different aircraft categories for the various engine operating modes.

Step 10. Estimate hourly emissions for aircraft category i for each pollutant and grid element as follows:

$$EAFO_{ikl} = (VTO_i \cdot EF_{ilj} \cdot T_{jik}) + (VL_i \cdot EF_{ilj} \cdot T_{jik})$$

Step 11. Compute hourly emissions from all aircraft in each grid element by repeating Step 10 for all categories:

$$EAFO_{kl} = \sum_i E_{ikl}$$

Emissions From Ground Service Vehicles

Step 12. Identify ground service vehicle requirements for each aircraft type in each grid.

GSV_{imk} = ground service vehicle of type m which is required by aircraft type i in grid k.

Step 13. Determine service times for each vehicle for each aircraft.

ST_{im} = service time of ground support vehicle type m for aircraft type i.

Step 14. Determine fuel consumption rates for the different ground service vehicles.

FC_m = fuel consumption rate for ground service vehicle type m.

Step 15. For each type of ground service vehicle, identify the emission rate as a function of fuel consumption.

ER_{ml} = emission rate of ground service vehicle type m of pollutant 1.

Step 16. Locate the k grid elements in which ground service vehicles operate.

Step 17. Compute hourly emissions in each grid from activity of ground service vehicle type m servicing aircraft type i.

$$EGSV_{imkl} = \frac{1}{2} V_i \cdot GSV_{imk} \cdot ST_{im} \cdot FC_m \cdot ER_{ml} ,$$

where:

$EGSV_{ik}$ = emissions of pollutant 1 from ground service vehicle type m in grid k, and

V_i = hourly volume of aircraft type i

= $VTO_i + VL_i$.

Step 18. Compute the total ground service vehicle emissions by grid by pollutant summing over all types of aircraft and ground service vehicles:

$$EGSV_{kl} = \sum_i \sum_m EGSV_{imkl} \cdot$$

Emissions From Fuel Storage and Handling

Step 19. Locate grid elements in which fuel is stored or handled.

Step 20. Identify types of fuel and volumes stored.

Step 21. Determine the mean daily high, low, and medium temperature for the month of interest.

Step 22. Determine the working loss factors for each of the three temperatures.

Step 23. Determine the daily volume of fuel pumped.

Step 24. Distribute the daily volume over 24 hours according to the diurnal flight activity pattern.

Step 25. Compute working losses for the hour of interest according to the volume of fuel pumped and the temperature applicable to the time of day as:

$EFSH_{kl}$ = emissions of pollutant l in grid k due to fuel storage and handling.

Emissions From Engine Testing and Maintenance

The data required to compute these emissions are classified. However, they are judged to be negligible and are neglected.

SCOTT AIR FORCE BASE

Emissions From Aircraft Flight Operations

Step 26. Identify the day of the week and the hour of the day for which emissions are to be estimated.

Step 27. Determine the active runway from the wind direction and/or aircraft category.

Step 28. For the time identified (Step 26), determine the activity factors for the different aircraft categories (jet and piston):

D_i = percent of monthly volume occurring on the given day of the week (aircraft i),

H_i = percent of daily volume occurring during the hour of interest (aircraft category i).

Step 29. For the active runway determined in Step 27, locate the k grid elements through which aircraft pass.

Step 30. Compute the total takeoff and landing volumes during the hour as follows (assume 1/2 landing and 1/2 takeoff):

$$V_i = \frac{M \cdot D_i \cdot H_i}{(OD_M)\ (10^4)},$$

where:

M = mean monthly air traffic volume.

Step 31. For the different aircraft categories, activity volumes, and grid elements identified above, determine the j engine operating modes for each grid element.

Step 32. Determine the time-in-mode for each aircraft category for each mode in each grid.

T_{jik} = time-in-mode j for aircraft category i in grid k.

Step 33. Identify the emission rates of the l pollutants, EF_{ilj}, of the different aircraft categories for the various engine operating modes.

Step 34. Estimate hourly emissions for aircraft type i for each grid element as:

$$EAFO_{ikl} = V_i \; EF_{ilj} \; T_{jik}$$

Step 35. Compute hourly emissions from all aircraft in each grid element by repeating Step 34 for all categories:

$$EAFO_{kl} = \sum_i EAFO_{ikl}$$

Emissions From Ground Service Vehicles

Step 36. Identify ground service vehicle requirements for each aircraft type in each grid.

GSV_{imk} = ground service vehicle of type m which is required by aircraft type i in grid k.

Step 37. Determine service times for each vehicle for each aircraft.

ST_{im} = service time of ground support vehicle type m for aircraft type i.

Step 38. Determine fuel consumption rates for the different ground service vehicles.

FC_m = fuel consumption rate for ground service vehicle type m.

Step 39. For each type of ground service vehicle, identify the emission rate as a function of fuel consumption.

ER_{ml} = emission rate of ground service vehicle type m of pollutant l.

Step 40. Locate the k grid elements in which ground service vehicles operates.

Step 41. Compute hourly emissions in each grid from activity of ground service vehicle type m servicing aircraft type i.

$$EGSV_{imkl} = 1/2\ V_i \cdot GSV_{imk} \cdot ST_{im} \cdot FC_m \cdot ER_{ml} ,$$

where:

$EGSV_{lk}$ = emissions of pollutant l from ground service vehicle type m in grid k, and

V_i = hourly volume of aircraft type i

= $VTO_i + VL_i$.

Step 42. Compute the total ground service vehicle emissions by grid by pollutant summing over all types of aircraft and ground service vehicles:

$$EGSV_{kl} = \sum_i \sum_m EGSV_{imkl} .$$

Emissions From Fuel Handling and Storage

Step 43. Locate grid elements in which fuel is stored or handled.

Step 44. Identify types of fuel and volumes stored. (Actual volume stored is classified. Assumed storage volume equals one month's supply at current usage rates.)

Step 45. Determine the mean daily high, low, and medium temperature for the month of interest.

Step 46. Determine the working loss factors for each of the three temperatures.

Step 47. Determine the daily volume of fuel pumped.

Step 48. Distribute the daily volume over 24 hours according to the diurnal flight activity pattern.

Step 49. Compute working losses for the hour of interest according to the volume of fuel pumped and the temperature applicable to the time of day as:

$EFSH_{kl}$ = emissions of pollutant l in grid k due to fuel storage and handling.

Emissions from Engine Testing and Maintenance

Step 50. Locate the grid elements in which engine testing occurs.

Step 51. Determine the testing schedule (frequency and times of occurrence) for the different types of engines tested.

Step 52. Determine testing cycle for each engine type.

TT_{jn} = time-in-mode j for engine type n.

Step 53. Apply the emission factors for the engine and modes to determine the emissions from engine testing:

$$EET_n = TT_{jn} \, EF_{jn} ,$$

where:

EET_n = emissions from testing engine type n.

Step 54. Determine the total emission factors from engine testing by summing over all engine types tested.

$$EET = \sum_n EET_n .$$

If engine testing occurs during specific hours, apply the emissions to these hours.

If it occurs randomly over a longer time period (e.g., an 8-hour working day, 24 hours, or a week), distribute the emissions equally over the time period.

CIVILIAN AIRPORTS

Emissions from Flight Operations at Controlled Airports

Step 55. Identify the month, day of the week, and hour of the day for which emissions are to be estimated.

Step 56. Determine the prevailing wind direction for the month.

Step 57. Determine the active runway from the wind direction and/or aircraft category.

Step 58. For the time identified (Step 1), determine the activity factors for the different aircraft types:

M_i = percent of annual volume occurring during the month (aircraft category i),

D_i = percent of monthly volume occurring on the given day of the week (aircraft category i),

H_i = percent of daily volume occurring during the hour of interest (aircraft category i).

Step 59. For the active runway determined in Step 2, locate the k grid elements through which aircraft pass.

Step 60. Compute the air traffic volume for the hour from:

$$V_i = \frac{A \cdot M_i \cdot D_i \cdot H_i}{(OD_M)\,(10^6)} ,$$

where the factors are defined in Steps 3 and 6 and the subscript i refers only to general aviation aircraft.

Step 61. For the different aircraft categories, activity volumes, and grid elements identified above, determine the j engine operating modes for each grid element.

Step 62. Determine the time-in-mode for each aircraft category for each mode in each grid.

T_{jik} = time-in-mode j for aircraft category i in grid k.

Step 63. Identify the emission rates of the l pollutants, EF_{ilj}, of the different aircraft categories for the various engine operating modes.

Step 64. Estimate hourly emissions for aircraft type i for each grid element:

$$EAFO_{ikl} = V_i \, EF_{ilj} \, T_{jik}$$

Emissions from Flight Operations at Uncontrolled Airports

Step 65. Determine the annual volume of air traffic from FAA Form 5010 and discussions with airport personnel.

Step 66. Determine the prevailing wind direction for the month.

Step 67. Determine the active runway from the wind direction and/or aircraft category.

Step 68. For the time identified for estimating emissions, determine the activity factors for the different aircraft types:

M_i = percent of annual volume occurring during the the month (aircraft category i),

D_i = percent of monthly volume occurring on the given day of the week (aircraft category i),

H_i = percent of daily volume occurring during the hour of interest (aircraft category i).

Step 69. For the active runway determined in Step 67, locate the k grid elements through which aircraft pass.

Step 70. Compute the air traffic volume for the hour from:

$$V_i = \frac{A \cdot M_i \cdot D_i \cdot H_i}{(OD_M)\,(10^6)} ,$$

Step 71. For the different aircraft categories, activity volumes, and grid elements identified above, determine the j engine operating modes for each grid element.

Step 72. Determine the time-in-mode for each aircraft category for each mode in each grid.

T_{jik} = time-in-mode j for aircraft category i in grid k.

Step 73. Identify the emission rates of the l pollutants, EF_{ilj}, of the different aircraft categories for the various engine operating modes.

Step 74. Estimate hourly emissions for aircraft type i for each grid element as:

$$EAFO_{ikl} = V_i \, EF_{ilj} \, T_{jik}$$

Step 75. Compute hourly emissions from all aircraft in each grid element by repeating Step 74 for all categories:

$$EAFO_{kl} = \sum_i EAFO_{ikl}$$

Step 76. Locate grid elements in which fuel is stored or handled.

Step 77. Identify types of fuel and volumes stored.

Step 78. Determine the mean daily high, low, and medium temperature for the month of interest.

Step 79. Determine the working loss factors for each of the three temperatures.

Step 80. Determine the daily volume of fuel pumped.

Step 81. Distribute the daily volume over 24 hours according to the diurnal flight activity pattern.

Step 82. Compute working losses for the hour of interest according to the volume of fuel pumped and the temperature applicable to the time of day as:

$EFSH_{kl}$ = emissions of pollutant l in grid k due to fuel storage and handling.

SECTION IX

IMPROVING ESTIMATES

Table 4 (page 2) displays the percent of emissions contribution by source at O'Hare Airport. Except for CO, aircraft are the predominate source of emissions, and even for CO they account for greater than two thirds. It is immediately evident then that an improved knowledge of aircraft operations will offer the most improvement in emissions estimation. There is the added benefit that a better knowledge of aircraft operations will improve the estimates for ground service vehicles and fuel handling and storage, since these depend ultimately on aircraft for their employment.

The first step would be to find precisely the volume and makeup of air traffic for a given hour. However, it is essentially impossible to predict accurately what will occur in a given hour. Since this probably accounts for the greatest uncertainty in the hourly emissions estimate, the greatest improvement would come about from actually gathering data during the period of interest.

After volume and makeup are known, the next important factor is time in mode, since this is the multiplying factor for a relatively constant emission rate for a given mode. There is not likely to be much variation in takeoff, climbout, approach, or landing times for a given type of aircraft, more variation will arise from idle and taxi time differences although even these were found to be fairly standard upon observation.

On this level of detail the actual pollutant for which emissions are being estimated becomes important. Idle and taxi modes have a relatively high emission rate for CO and hydrocarbons; NO_x emissions are higher during takeoff, climbout, and approach; and CO and NO_x emissions are high during landing.

Airport emissions cannot be precisely estimated due to all the influencing factors described in Section III. It is felt that the methodology given in this report strikes a good balance between maximum potential accuracy and the rapidly increasing level of effort required as estimates become incrementally more precise.

SECTION X

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OFF-HIGHWAY MOBILE SOURCE INVENTORY

FOREWORD

The work described in this report was performed by Southwest Research Institute for the U.S. Environmental Protection Agency under Contract No. 68-02-1397, "Methodology for Estimating Emissions from Off-Highway Sources for the RAPS Program." The project grew out of RFP No. DU-74-A041 and SwRI's responding Proposal No. 11-9962, dated January 7, 1974. The project was initiated on March 12, 1974; and the technical effort was completed on September 30, 1974. It was identified at SwRI as Project No. 11-3916.

The project leader for SwRI has been Charles T. Hare, Manager, Advanced Technology, Department of Emissions Research. Overall supervision has been provided by Karl J. Springer, Director, Department of Emissions Research. Project Officer for the Environmental Protection Agency has been Charles C. Masser, National Air Data Branch.

ABSTRACT

Emissions, population, and usage data existing in the technical literature have been collected and organized for the following unregulated sources: outboard motors, snowmobiles, motorcycles, lawn and garden equipment, construction equipment, industrial equipment, and farm equipment. The investigation has been limited to mobile sources utilizing internal combustion engines and thus has not included plant processes or stationary engines.

Sources of data for individual counties have been compiled, mostly items which may have some correlation with equipment population, usage, or emissions. Data found in these sources have been restated only where necessary to other phases of the program.

Methodologies for estimating emissions and fuel consumption on a county basis have been developed for the sources noted above. They have been demonstrated for counties in the St. Louis Metropolitan Air Quality Control Region (AQCR 070), and their strengths and weaknesses have been discussed. Methods have also been developed to apportion county emissions estimates to grid elements, but they have not been demonstrated. The exhaust constituents assessed include hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), particulate, aldehydes (RCHO), and oxides of sulfur (SO_x). For outboard motors, neither particulate nor aldehyde data were available; but carbon dioxide (CO_2) emissions were included.

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I. INTRODUCTION

This study is an extension of previous work by SwRI on emissions from uncontrolled mobile sources using internal combustion engines, with emphasis on estimates for counties and smaller areas. Prior studies conducted at SwRI under Contract No. EHS 70-108 have been responsible for the development and/or publication of a substantial fraction of available data for a number of engine categories. These categories include locomotives, outboard motors, motorcycles, small utility engines, farm equipment, construction equipment, industrial equipment, gas turbine electric utility powerplants, and snowmobiles.

Of the categories noted above, seven were studied during this project (outboards, snowmobiles, motorcycles, lawn and garden, construction, industrial, and farm). The first objective was to compile and summarize all available data on emissions, population, and usage of engines in these categories. Sources consulted were reports for EPA and other agencies, technical papers, state motor vehicle registration departments, statistical publications, and others.

Another objective was to compile a list of data sources for counties and other small areas, and the results of this effort appear as Appendix B. Although a great deal of direct information on engine emissions, population, and usage is not available for counties, sufficient data were uncovered which are relatable to the desired variables to have made the effort worthwhile. The final objectives of this study were to derive methodologies for estimating emissions down to the county and grid element levels,and to demonstrate the county methodologies for AQCR 070 (St. Louis Metropolitan). Even having accomplished these tasks, the problem remains that no data are available against which the derived results can be checked.

II. SUMMARY OF NATIONAL AND STATE DATA ON EQUIPMENT POPULATIONS, USAGE, AND EMISSIONS

Engines for which emission estimation methodologies have been developed under the subject program are used in a wide variety of leisure and utilitarian applications. They represent all major non-automotive engine markets up to about the 500 horsepower class. As a consequence of this diversity in size, type, and field of application, data relating to population, usage, and emissions of the engines are widely scattered in the literature. This section of the report will summarize pertinent data found for each engine category, as a matter of convenience and for future reference.

A. OUTBOARD MOTORS

Data on the population of outboard motors or outboard boats and their distribution by state are available through the U.S. Coast Guard(1) and The Boating Industry magazine(2). Calendar year 1973 outboard boat registrations in the 48 contiguous states plus the District of Columbia totalled 4.98 million, but some states did not register all outboard boats operating on their waters. All registration exemptions for small boats ran out at the end of 1973, however, so the 1974 registration total (available in 1975) should show a strong increase due to inclusion of a number of previously unregistered craft. The 1973 Boating Industry total for outboard motors in the same states was 7.51 million, but the exact basis for this figure is not known.

Breakdowns of the USCG(1) 1973 outboard boat registrations and the Boating Industry(2) 1973 outboard motor population by state are given in Appendix A, Tables A-1 and A-2, respectively. The reliability of boat population figures for 14 states will be in doubt until 1974 registration figures become available, but a correction for unregistered boats can be estimated using an analysis of the total U.S. outboard motor population by rated power category(3, 4). Assuming that boats in the power categories 0-6.9 hp and 7.0-19.9 hp are uniformly distributed within the categories, the correction factors shown in Table 1 can be used with corresponding state registrations to come up with more

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*Numbers in parentheses indicate list of References at the end of this report.

Table 1. FACTORS TO CORRECT 1973 STATE OUTBOARD BOAT REGISTRATIONS FOR EXEMPTION OF SMALLER CRAFT

Exemption	State(s)	Calculated	
		% Unregistered	Correction factor
5 hp or below	TN, WV, WY	22.5	1.29
7.5 hp or below	MD, MO	32.5	1.48
8 hp or below	MT	33.6	1.51
9.9 hp or below	ND	37.6	1.60
10 hp or below	AR, FL, GA, LA, ME, MS, NC	37.8	1.61

representative values. Performing this correction for all the states exempting very small craft yields an additional 0.51 million outboard boats, making the estimated current total about 5.5 million.

Relatively little good information is available on usage of outboard motors or outboard boats, so estimates have been used previously(3) to compute the national impact of outboards. It is expected that climatic conditions have a strong influence on outboard usage, so the usage aspect will be handled with the emissions estimation methodology in Section IV. Several studies have been conducted on outboard motor emissions(3-6), but only the first one (References 3 and 4) has been published at this time. In examining outboard motor emissions data from all investigations, attention must be paid to segregating emissions computed or measured to be ending up in the atmosphere from those ending up in the water. Depending on the exhaust constituent of interest, fractions going through the water to the atmosphere range from 40 or 50 to nearly 100 percent. Emission factors for use in making small-scale atmospheric emission estimates are presented in Table 2, along with fuel consumption factors. It is anticipated that emission factors in grams per motor hour and fuel consumption factors in gallons per motor hour will be the most useful of those given, but factors are also given in other units for convenience.

A number of states keep data on registration of outboard boats and/or outboard motors by county, but requests for such data were not sent to all states. In the course of looking for socioeconomic data, however, a number of state statistical publications were obtained which contained boat registration data. County registrations were obtained in this manner for New York(7), Ohio(8), South Carolina(9), and Wisconsin(10); but some of these data were out of date by as much as seven years.

Table 2. AIR POLLUTANT EMISSION FACTORS AND FUEL CONSUMPTION FOR OUTBOARD MOTORS

Fuel consumption		Atmospheric exhaust emissions					
Units	Value	Units	HC	CO	CO_2	NO_x	SO_x
g/rated hp hr	174.	g/rated hp hr	31.3	92.7	143.	0.18	0.18
gal/rated hp hr[b]	0.0622	g/motor hr[a]	769.	2,280.	3,510.	4.5	4.4
kg/motor hr[a]	4.28	g/gal fuel[b]	503.	1,490.	2,300.	3.0	2.9
gal/motor hr[a, b]	1.53						

[a] Based on average motor rated horsepower of 24.6.

[b] Based on fuel density of 6.17 lb_m/gal = 0.739 g/ml.

B. SNOWMOBILES

Registration of snowmobiles by state is summarized at least annually by the International Snowmobile Industries Association (ISIA), and the latest data available are dated March 1, 1974(11). The total of all U.S. registrations as given in the ISIA data is 1.71 million, and an additional 0.86 million are listed for Canada. Tabulation of all the state registrations is given in Table A-3 of Appendix A. In addition to the ISIA data, the only information found on snowmobile population was registration data by county for New York(7).

Annual usage of snowmobiles is not a well-defined quantity, and all values used in the literature to date have been estimated(12-14). The estimates used in the referenced publications were 60 hr/yr and 100 hr/yr, respectively, the former figure being based on qualitative information from a number of sources. For lack of information to the contrary, the 60 hr/yr estimate will be adopted for the purposes of this report.

Data on exhaust emissions from snowmobile engines are available from three sources(12-16), although information from Reference 12 (and Reference 13, which is based on Reference 12) is much more comprehensive and complete than that from the others. Reference 16 contains rudimentary raw data (one speed, several loads and mixtures) on one engine, and Reference 14 develops an emission factor based on the same engine. Reference 15 contains basic data (one speed, one load, several mixtures) on one engine and no real attempt at computing an emission factor. Reference 12 includes data on four engines (three 2-strokes and one rotary), each of which was operated at 29 speed/load conditions using manufacturers' recommended carburetor settings. Where possible, all these data will be taken into consideration; but it is obvious that data from Reference 12 will be relied upon most heavily.

Emission factors and fuel consumption for 2-stroke snowmobiles have been computed in several sets of units, and they are presented in Table 3. The emissions values obtained for a rotary snowmobile engine(12) are not included in Table 3, because they were different than 2-stroke levels in several cases. It should be noted that the values are based on tests of only one engine, a 35 hp unit, and that care must be exercised in choice of scaling factors when the data are used to represent other rotaries. Emission factors and fuel consumption for rotary-engined snowmobiles are given in Table 4 in several sets of units. Factors from both Tables 3 and 4 can be used for snowmobile populations where the fraction of each type in the population is known or can be estimated. The OMC rotaries have been on the market less than three seasons as of now (10/74); so if the population breakdown is not available, only small errors would be introduced by assuming that the population is all of the 2-stroke type and using factors from Table 3.

Table 3. EMISSION FACTORS AND FUEL CONSUMPTION FOR SNOWMOBILES WITH 2-STROKE ENGINES

	Emission factors(12)						Emission factors(14)		
Units	HC	CO	NO_x	Part.	RCHO	SO_x	HC	CO	NO_x
g/rated hp hr	23.1	35.9	0.367	1.02	0.34	0.031	29.	105.	0.32
g/unit hr	630.	978.	10.0	27.9	9.2	0.85	580.	2100.	6.40
g/gal fuel	670.	1000.	11.	30.	9.8	0.90	-	-	-
kg/unit yr	37.8	58.7	0.60	1.67	0.55	0.05	58.	210.	0.64

Fuel consumption(12)

Units	Value
g/rated hp hr	97.
gal/rated hp hr	0.035
kg/unit hr	2.6
gal/unit hr	0.94
kg/unit yr	160.
gal/unit yr	56.

Notes:

average rated hp = 20(14) or 27.22(12)

annual usage = 100 hr(14) or 60 hr(12)

average load factor = 0.50(14) or 0.210(12)

fuel density = 6.2 lb_m/gal = 0.743 g/ml

C. MOTORCYCLES

Motorcycle registrations by state are compiled by the U. S. Department of Transportation, Federal Highway Administration. These data are published annually in Statistical Abstract of the United States(17), Highway Statistics(22), and elsewhere. Another source for reasonably accurate state registration data is Automotive Industries(18) magazine,

Table 4. EMISSION FACTORS AND FUEL CONSUMPTION FOR ROTARY-ENGINE SNOWMOBILES(12)

Fuel consumption		Emission factors					
Units	Value	Units	HC	CO	NO_x	Part.	SO_x
g/rated hp hr	124.	g/rated hp hr	4.14	71.7	0.61	0.29	0.052
gal/rated hp hr	0.044	g/unit hr	145.	2510.	21.2	10.2	1.81
kg/unit hr	4.3	g/gal fuel	94.	1600.	14.	6.6	1.2
gal/unit hr	1.54	kg/unit yr	8.70	151.	1.27	0.61	0.11
kg/unit yr	260.						
gal/unit yr	92.						

Notes: rated hp = 35
annual usage = 60 hr
average load factor = 0.217
fuel density = 6.2 lb_m/gal = 0.743 g/ml

and this source has a shorter time lag than the official government publications. The latest registration data available now are for 1973(18), indicating total U.S. registered motorcycles to be about 4.36 million. A recent national survey(19) indicates that 21 percent of all motorcycles may be unregistered, bringing the estimated national total to 5.52 million units. The 1973 registrations by state mentioned above are tabulated in Table A-4 of Appendix A.

A great deal of information is available now regarding motorcycle usage, but none of it is without flaws. The most comprehensive sources are two statistical surveys(19, 20) conducted quite recently by a marketing research firm. The major problems with these data are: (1) that all survey participants were city residents, and (2) that the researchers used a "median average" rather than the arithmetic mean for expressing yearly mileage to compensate for what they felt to be respondent or interviewer errors resulting in high mileage figures. The influence of sampling only in cities cannot be estimated quantitatively, but a recent publication on fuel usage estimation by county(21) indicates annual light-duty vehicle mileage in rural areas may be significantly greater than that in urban areas. How well this directional generality would work for motorcycles is not known.

Annual mileage data in terms of medians and means from the two surveys(19, 20) are shown in Table 5 as functions of engine size and type. Most of the trends from the two surveys compare rather well, but the median average mileages are grossly different. This result is difficult to explain in view of the very good agreement of the overall mean averages;

Table 5. ANNUAL MILEAGE DATA[a] FOR MOTORCYCLES BY ENGINE TYPE AND SIZE

Engine size	Annual mileage by type(19)			Annual mileage by type(20)		
	2-stroke	4-stroke	All	2-stroke	4-stroke	All
90cc or less	828	1,560	1,152	620	480	560
91-190cc	1,644	1,980	1,764	1,170	1,240	1,170
191-290cc	1,968	3,000	2,232	1,630	1,300	1,570
over 290cc	2,796	4,464	3,948	2,420	2,740	2,580
All	1,896	3,456	2,280	1,420	1,870	1,590
	Mean average		3,276	Mean average		3,460

[a]"Median average" mileages except where otherwise noted.

and in combination with other mathematical and logical errors in the survey analyses, the disagreement makes strong confidence in the overall survey results impossible.

Other mileage estimates for motorcycles(22, 23) have been largely a matter of speculation, except one set of figures released in 197[illegible] by the Motorcycle Industry Council (MIC)(24). These estimates were 1[illegible]0 miles per year for machines under 100cc, 2500 miles per year for 100-199cc units, 3000 miles per year for bikes in the 200-299cc class, and 4500 miles per year for units 300cc or larger. Even with all the information available, there is not a clear-cut choice of existing mileage data which is obviously accurate. Consequently, the estimates in Table 6 are recommended in lieu of more reliable information. The population percentages

Table 6. MILEAGE ESTIMATES RECOMMENDED FOR MOTORCYCLES AND POPULATION BREAKDOWNS

Engine size	Annual mileage	% of population(19)	% of population(19)	
			2-stroke	4-stroke
90cc or less	750	21	11	9
91- 90cc	1400	27	19	8
191-290cc	2100	11	8	3
over 290cc	3000	41	13	29
National mean	199[illegible]	Overall	51	49

[a]Computed using population percentages from Reference 19.

by engine size in Table 6 can be used for the nation as a whole, but more accurate regional size breakdowns(19) are given in Appendix A, Table A-5. The breakdown by engine type in Table 6 can be used for all areas. It should be noted that where parts of an Air Quality Control Region (AQCR) fall into two or more motorcycle "regions", it would probably be logical to use compromise population percentages by engine size for the entire area rather than use different ones on either side of a boundary.

Data on emissions from motorcycles are available from several sources(25-27), but those given in Reference 25 (and refined in Reference 26, a paper based on Reference 25) are by far the most comprehensive. Emissions data given in the Olson report(28) are not useful in computing emission factors due to the inaccuracy of the old procedures used. Factors listed by AESi in its report to the California Air Resources Board(27) are essentially equal to those developed by SwRI in its report to the Environmental Protection Agency(25) and almost equal to the refined factors(26).

If a simplified calculation of motorcycle emissions is desired, data from Table 6 can be used in conjunction with emission factors from Table 7. A more detailed analysis can be performed (by "region", as defined in Table A-5) by using emission factors from Table 8 and population breakdowns from Table 6. These factors can be expressed in other units when the annual mileage estimate from Table 6 is used, and the results

Table 7. GENERALIZED MOTORCYCLE EMISSION FACTORS AND FUEL CONSUMPTION BY ENGINE TYPE

Application	Engine type	Data ref.	Emissions in grams per mile						Fuel, mi/gal
			HC[a]	CO	NO_x[b]	Part.	RCHO	SO_x	
on-road	2-s	25	16.	27.	0.12	0.33	0.11	0.038	-
		26	17.	30.	0.11	0.36	0.12	0.040	41
		27	16.	27.	0.12	0.33	-	-	-
	4-s	25	3.5	33.	0.24	0.046	0.047	0.022	-
		26	3.6	34.	0.23	0.048	0.050	0.023	44
		27	3.5	33.	0.24	0.04	-	-	-
off-road	2-s	27	24.	32.4	0.06	0.33	-	-	-
	4-s	27	4.0	39.6	0.36	0.04	-	-	-

[a] Includes an allowance for evaporative emissions.

[b] Does not reflect correction to new driving schedule for testing smaller (under 170cc) motorcycles(29).

Table 8. MOTORCYCLE EXHAUST EMISSION FACTORS AND FUEL CONSUMPTION PER UNIT DISTANCE BY ENGINE TYPE AND SIZE

Engine size	Emissions from 2-stroke motorcycles in grams per mile						Fuel usage, mi/gal
	HC	CO	NO_x	Part.	RCHO	SO_x	
90cc or less[a]	6	6	0.11	0.14	0.10	0.021	80
91-190cc[a]	10	12	0.10	0.19	0.11	0.025	69
191-290cc	18	30	0.04	0.35	0.13	0.043	40
over 290cc	25	50	0.04	0.55	0.14	0.057	30

Engine size	Emissions from 4-stroke motorcycles in grams per mile						Fuel usage, mi/gal
	HC	CO	NO_x	Part.	RCHO	SO_x	
90cc or less[a]	2.2	20	0.22	0.022	0.018	0.014	88
91-190cc[a]	2.6	24	0.20	0.030	0.026	0.017	74
191-290cc	3.4	32	0.17	0.045	0.044	0.022	56
over 290cc	4.8	46	0.11	0.070	0.079	0.031	40

[a] Only the NO_x values have been corrected to reflect the new smaller-bike (under 170cc) cycle(29).

are given in Table 9. Note that all the factors developed thus far except those given in Table 7 include no evaporative emissions. The data and method required to estimate evaporative emissions will be presented with the county motorcycle emissions estimation methodology in Section IV.

D. LAWN AND GARDEN EQUIPMENT

In estimating the number of small utility engines used nationwide in lawn and garden equipment, there are no registration statistics and very few reliable data on sales or production. The best estimates available at present are summarized in Table A-6 of Appendix A(14, 30, 31), and they are discussed and evaluated in a previous report to the Environmental Protection Agency(32) and a technical publication based on that report(33). In attempting to account for utility engines used for lawn and garden applications, a major supposition is that the equipment should be distributed more or less in proportion to the number of single-unit housing structures. It has also been assumed that a rough balance should occur between extra units operated on commercial or public property and homes which have no engine-powered equipment. A good check on these assumptions is to note

Table 9. MOTORCYCLE ANNUAL EXHAUST EMISSION FACTORS AND FUEL CONSUMPTION BY ENGINE TYPE AND SIZE

Engine size	Emissions from 2-stroke motorcycles in kg per year						Fuel usage, gal/yr
	HC	CO	NO_x	Part.	RCHO	SO_x	
90cc or less[a]	4.5	4.5	0.082	0.10	0.075	0.016	9.4
91-190cc[a]	14.	17.	0.14	0.27	0.15	0.035	20.
191-290cc	38.	63.	0.08	0.74	0.27	0.090	52.
over 290cc	75.	150.	0.12	1.65	0.42	0.17	100.

Engine size	Emissions from 4-stroke motorcycles in kg per year						Fuel usage, gal/yr
	HC	CO	NO_x	Part.	RCHO	SO_x	
90cc or less[a]	1.6	15.	0.16	0.016	0.014	0.010	8.5
91-190cc[a]	3.6	34.	0.28	0.042	0.036	0.024	19.
191-290cc	7.1	67.	0.36	0.094	0.092	0.046	38.
over 290ccc	14.	140.	0.33	0.21	0.24	0.093	75.

[a] Only the NO_x values have been corrected to reflect the new smaller-bike (under 170cc) cycle(29).

that the 1970 census(17) showed 46.8 million single-unit housing structures (49.6 million projected to the present), while the population of lawnmowers (alone) projects to about 45.6 million at present. This sort of agreement is quite reasonable and tends to support the overall assumptions.

Based on data from Table A-6 and assuming a growth rate of 6 percent per year for the population of lawn and garden equipment since 1968, the equipment populations basic to this estimation methodology are presented in Table 10. Usage of lawn and garden equipment undoubtedly

Table 10. ASSUMED POPULATIONS OF LAWN AND GARDEN EQUIPMENT (10/31/74)

Engine type	Typical rated hp	Engines in service
4-stroke	3.5	50.9×10^6
2-stroke	3.0	3.5×10^6
Snowthrowers	3.5 (approx.)	1.5×10^6
Other equipment	3.5 (approx.)	52.9×10^6
Total		54.4×10^6

varies with climate, but a well-founded overall estimate of average usage is 50 hours per year(14). A method has been developed to correct individual county emissions for climate utilizing mean frost-free days per year as basis, and it will be discussed in Section IV as the methodologies are outlined.

Data on emissions from small utility engines are available in several References(14, 16, 27, 32, 33) representing the results of three independent studies. The study reported on in References 14 and 16 was a limited laboratory investigation of 36 engines, with 29 4-stroke engines and seven 2-stroke engines in the sample. Reference 27 reports on a study in which eleven machines (eight 4-stroke and three 2-stroke) were operated through their normal tasks (cutting grass, tilling, etc.) while their exhausts were collected via a large bag or a constant-volume sampler. These data may be closer to real-life emissions than any other information available at this time. The work reported on in References 32 and 33 was an intensive laboratory study of five engines, with one 2-stroke engine and four 4-strokes in the group investigated. Some degree of effort was expended by the original researchers or by others on development of emission factors and emissions impact using each of the three studies as basis.

Hourly mass emissions and fuel consumption for the lawn and garden applications of small utility engines are given in Table 11 as estimated according to each of the major studies conducted. Data from studies described in References 27 and 32 are considered to be most representative, so a compromise set of emission factors has been drawn up using these references as basis and is presented as Table 12. These factors can be used with the methodology as outlined in Section IV to estimate emissions on a county basis.

Table 11. EMISSION FACTORS FOR LAWN AND GARDEN EQUIPMENT BY TYPE OF ENGINE AND SOURCE OF INFORMATION

Engine type	Data from reference	Emissions in grams per hour						Fuel usage, gal/hr
		HC	CO	NO_x	Particulate	RCHO	SO_x	
4-stroke	16	19.	333.	5.2	-----	---	---	-----
	27	40.	380.	4.0	0.7[a]	---	---	0.177
	32	34.	380.	4.3	0.6	0.7	0.5	0.21
2-stroke	16	170.	418.	1.2	-----	---	---	-----
	27	280.	650.	2.0	10.[a]	---	---	0.400
	32	300.	670.	2.2	9.4	2.8	0.8	0.41

[a] Adopted from Reference 32 by author of Reference 27.

Table 12. RECOMMENDED EMISSION FACTORS AND FUEL USAGE FOR LAWN AND GARDEN EQUIPMENT

Units of factor	Engine or equipment	Emission factors						Fuel usage	
		HC	CO	NO_x	Part.	RCHO	SO_x	Value	Units
g/hr	4-s (all)	37.	380.	4.2	0.6	0.7	0.5	0.20	gal/hr
	2-s snowthrower	350.	770.	2.4	11.	3.3	0.9	0.47	gal/hr
	Other 2-s	300.	660.	2.1	9.4	2.8	0.8	0.40	gal/hr
kg/yr[a]	4-s snowthrower	0.19	2.0	0.02	0.00	0.00	0.00	1.1	gal/hr
	2-s snowthrower	1.9	4.1	0.01	0.06	0.02	0.00	2.5	gal/hr
	Other 4-s	1.8	19.	0.21	0.03	0.04	0.02	10.	gal/hr
	Other 2-s	15.	33.	0.01	0.47	0.14	0.04	20.	gal/hr

[a] Assuming 40 inches snowfall for snowthrowers and a 213 day season for other equipment.

E. CONSTRUCTION EQUIPMENT

Although the project considered construction and industrial equipment as a single category, it now seems more reasonable to consider them separately and thereby reduce the risk of logical errors. In conjunction with efforts toward developing emission factors, a number of sources(27, 34-38) provide estimates of construction equipment populations. In two of these References(27, 38), the scope was limited to a single state; so populations estimated therein are not general enough for present purposes. Another study(37) made no distinction between construction and industrial equipment usage, so its population figures cannot be used here. Two more References(35, 36) do not make use of explicit equipment populations, but rather a total horsepower-hour figure, in estimating emissions impact. By elimination, Reference 34 is the only usable source of population data on construction equipment. Table 13 summarizes these estimates by equipment category, along with data from several sources on typical machine horsepower and annual usage.

Since the result required from this section for input to the county construction equipment methodology is total national construction equipment emissions, only three References(34, 35, 36) can be used for final comparison. Emission factors developed in some of the other studies, however, are useful for indicating the range of estimates available; and all the factors available are included in Table A-7 of Appendix A. Values for national construction equipment emissions are given in Table 14, including amounts estimated for earthmoving equipment as well as all equipment categories. Agreement between estimates for earthmoving equipment is reasonably good, although entirely different assumptions were made for the estimate in Reference 34 as compared to the other two.

Table 13. ESTIMATES OF CONSTRUCTION MACHINERY POPULATIONS, USAGE, AND RATED HORSEPOWER

Equipment category	Estimated population(34)	Est. usage, hr/yr Ref. 27[a]	Ref. 34	Ref. 36	Estimated power, hp Ref. 27[a]	Ref. 34
Tracklaying tractors	197,000	1350	1050	1500	140	120
Tracklaying loaders	86,000	1700	1100	2000	240	65
Motor graders	95,300	2000	830	1200	105	90
Scrapers	27,000	1000	2000[b]	2000	475	475
Off-highway trucks	20,800	2400	2000[b]	2200	420	400
Wheel loaders	134,000	1400	1140	2000	140	130
Wheel tractors	437,000	900	740	----	82	75
Rollers	81,600	700	740	----	78	75
Wheel dozers	2,700	1800	2000	----	330	300
General purpose	100,000	600	1000	----	115	120

[a] These estimates are not considered entirely independent of those in Reference 34 and are intended for California only.

[b] These estimates are not independent of those in Reference 36.

Table 14. ESTIMATES OF NATIONAL CONSTRUCTION EQUIPMENT EMISSIONS AND FUEL CONSUMPTION

Equipment categories	Fuel	Ref.	Emissions in kg/yr x 10^{-6} HC	CO	NO_x	Part.	RCHO	SO_x	Fuel, 10^6 gal/yr
All const.	Diesel	34	72.	220.	820.	63.	17.	65.	4615.
	Gasol.	34	56.	1100.	36.	2.2	1.	1.6	602.
Earth-moving	Diesel	35[a]	55.3	164.	376.	----	---	----	3609.[c]
	Diesel	36[b]	39.9	202.	567.	18.1	---	97.0	3874.[c]
	Diesel	34	57.4	160.	529.	34.8	10.	42.3	3368.

[a] Estimate for 1969 made in 1970.

[b] Estimate for 1969 made in 1972.

[c] Assuming a BSFC of 0.44 lb_m/hp hr = 200 g/hp hr, fuel density = 0.86 g/ml.

F. INDUSTRIAL EQUIPMENT

This category of engines includes a relatively large number of small utility engines similar to those used in lawn and garden equipment and a much smaller number of more durable, more expensive engines of the heavy-duty type. Treating the heavy-duty class first, it includes items such as fork lift engines, auxillary engines used on mobile equipment, engines used in the mineral industries, and pump and generator engines used by airports and utilities. The major source of information on this class of equipment is a previous report to the Environmental Protection Agency(34), in which engine populations and size distributions were estimated on the basis of engine shipments and their value. These estimates are presented in Table 15 along with assumptions on annual engine usage which are about one-half the numbers of hours estimated earlier for comparably-sized construction equipment.

Table 15. ESTIMATES OF HEAVY-DUTY INDUSTRIAL ENGINE POPULATION, RATED POWER, AND ANNUAL USAGE(34)

Engine type	Typical rated hp	Annual usage, hr/yr	Population
Diesel	125	600	417,000
Gasoline	55	300	990,000

The light-duty gasoline engines used in industry are assumed to be the relatively inexpensive air-cooled type. The population of these engines can be estimated by extending the method used in Reference 34 and by assuming that: (1) useful life of these engines averages 600 hours and (2) annual usage averages 100 hours. The resulting population estimate for light-duty industrial gasoline engines is 5.8 million units, and average rated horsepower is estimated at 3.86(34).

Information on emissions from one or more types of industrial engines is found in several of the same sources already utilized(27, 33, 34, 37). Reference 37 is limited in scope to industrial tractors only, but the specific emissions data are useful for comparison. Reference 27 contains original emissions data only on light duty gasoline engines. Emissions data from these sources are summarized in Table 16 along with fuel consumption estimates and a compromise figure is given for emissions from the light-duty class of industrial engines. The total of estimated annual emissions can be used with the methodologies developed in Section IV to estimate county and grid emissions totals.

Table 16. EMISSIONS AND FUEL CONSUMPTION OF INDUSTRIAL ENGINES

			Emissions					
Engine type	Ref.	Units	HC	CO	NO_x	Part.	RCHO	SO_x
Heavy-duty diesel	34	g/hp hr	1.12	3.03	14.0	1.00	0.21	0.931
	37[a]	g/hp hr	2.7	6.5	8.3	-	-	-
	34	10^6 kg/yr	18.2	49.3	228.	16.2	3.4	15.1
Heavy-duty gasoline	34	g/hp hr	6.68	199.	5.16	0.327	0.22	0.268
	37[a]	g/hp hr	2.8	163.	7.8	-	-	-
	34	10^6 kg/yr	86.5	1690.	43.8	2.8	1.9	2.3
Light-duty gasoline	27[b]	g/hr	50.0	600.	10.0	0.7	-	-
	33	g/hr	29.2	386.	7.68	0.68	0.72	0.60
	c	g/m	32.	400.	7.3	0.68	0.72	0.60
	c	10^6 kg/yr	19.	230.	4.2	0.39	0.42	0.35

		Fuel	
Engine type	Ref.	Units	Value
Heavy-duty diesel	34	g/hp hr	211.
	37[a]	g/hp hr	193.
	34	10^6 gal/yr	1067.
Heavy-duty gasoline	34	g/hp hr	312.
	37[a]	g/hp hr	243.
	34	10^6 gal/yr	941.
Light-duty gasoline	27[b]	gal/hr	0.300
	33	gal/hr	0.25
	c	gal/hr	0.23
	c	10^6 gal/yr	133.

[a] Industrial wheel tractors only.

[b] Category called "home utility" in reference.

[c] Compromise between estimates given in References 27 and 33, based on 3.86 average engine hp.

G. FARM EQUIPMENT

The population of farm equipment is quite well defined down to the county level due to the availability of the Census of Agriculture(39). This reference can be considerably out of date, since it is published at five-year intervals, but the equipment populations change slowly enough so that most of the data remain reasonably accurate. The edition used in preparing this report was for 1969, and a new one (dated 1974) should be out in 1976. Data given in this reference are much too voluminous to be included here, but copies of the whole document are available in most libraries.

Farm equipment usage information is available in the form of estimates from several sources(33, 34, 37, 38), but accurate survey data are not available. The estimates are summarized in Table 17, along with

Table 17. SUMMARY OF MOTORIZED FARM EQUIPMENT ANNUAL USAGE ESTIMATES

Type of equipment	Ref.	Estimated annual usage, hours	Typical power, hp	Typical load factor
Diesel tractor	34	490	80.2[a]	0.57
	37	432	78.4[a]	0.43
	38[b]	600	80.4	0.57
Gasoline tractor	34	291	40.9[a]	0.57
	37	282	39.7[a]	0.36
	38[b]	500	50.5	0.57
Self-propelled combine	34	73	110.	0.52
	38[b]	100	120/105[c]	0.52
Pull combine	34	52	25.	0.52
	38[b]	100	120/105[c]	0.52
Balers	34	24	40.	0.52
	38[b]	60	70/50[c]	0.52
Forage harvesters	34	120	140.	0.52
	38[b]	100	150/110[c]	0.50
Miscellaneous heavy-duty	34	50	30.	0.52
	38[b]	50	60/30[c]	0.50
Miscellaneous light-duty	34	50	3.5	0.40

[a] Flywheel hp
[b] California only
[c] Estimates for diesel/gasoline equipment.

values for the typical horsepower and load factor of each category of equipment. Estimates given in References 34 and 37 for tractors are in very good agreement, but those in Reference 38 show much higher usage. It should also be noted that tractor horsepower estimates in Reference 38 apparently do not include a correction for power train losses. It is recommended that the values of usage and horsepower from Reference 34 be used when computing emissions from a given area due to their consistent availability, but estimates for tractors could be made using Reference 37 with little change in overall values. Usage of estimates from Reference 38 should at least be restricted to California, and the power loss correction noted above should be made for any calculation involving tractors.

In order to be usable in the emissions estimation methodology without modification, farm equipment emission factors should be expressed in kg/hr. This step is presented as Table 18 for data from several references, along with information on fuel consumption. Hourly emission factors from all the sources are in reasonably good agreement for diesel tractors, and the disagreements for gasoline tractors stem primarily from the variation in load factors shown by Table 17 (these comments also apply to fuel consumption). Since the emission factors from Reference 38 are derived mainly from those in Reference 34, the more complete documentation of Reference 34 makes it the logical choice over Reference 38 for all categories. Making a choice between References 34 and 37 in the gasoline tractor category, however, is a more difficult problem. For hydrocarbons, the choice would have to be Reference 34 due to the greater accuracy of the analytical method used (FID rather than NDIR). A compromise between values given in References 34 and 37 for CO, NO_x, and fuel consumption would probably be most appropriate, resulting in factors of 2.86, 0.134, and 5.08 kg/hr, respectively.

Table 18. EMISSION FACTORS AND FUEL CONSUMPTION FOR FARM EQUIPMENT

Equipment type	Ref.	Emission factors, kg/hr						Fuel[a], kg/hr
		HC	CO	NO_x	Part.	RCHO	SO_x	
Diesel tractor	34	0.078	0.154	0.429	0.059	0.016	0.040	9.06
	37	0.092	0.221	0.282	-----	-----	-----	8.06
	38	0.063	0.139	0.426	0.050	-----	0.040	8.23
Gasoline tractor	34	0.208	3.34	0.155	0.008	0.007	0.006	6.30
	37	0.041[b]	2.38	0.113	-----	-----	-----	3.86
	38	0.197	4.11	0.190	0.010	-----	0.007	6.94
Self-propelled combine	34	0.300	6.37	0.408	0.054	0.015	0.034	15.3
	38	0.259	6.50	0.417	0.055	-----	0.033	12.6
Pull combine	34	0.116	2.83	0.068	0.005	0.003	0.004	4.25
Baler	34	0.183	4.53	0.109	0.008	0.005	0.006	6.80
	38	0.179	5.33	0.148	0.012	-----	0.007	6.34
Forage harvester	34	0.122	0.297	0.657	0.110	0.022	0.067	15.2
	38	0.171	2.25	0.612	0.098	-----	0.060	14.3
Miscellaneous heavy-duty	34	0.082	1.73	0.112	0.015	0.004	0.009	4.17
	38	0.079	1.70	0.175	0.025	-----	0.015	4.71
Miscellaneous light-duty	c	0.029	0.363	0.007	0.001	0.001	0.001	0.58

[a] Where necessary, densities assumed were 0.731 g/ml for gasoline and 0.851 g/ml for diesel fuel.

[b] Based on NDIR data.

[c] Based on factors for light-duty industrial engines, Table 16.

III. SOURCES OF DATA ON COUNTIES

Amid all the information available in the literature on subjects which bear on this study, very little is available for the county level. The major sources of county data utilized are given in Table 19, along

Table 19. MAJOR SOURCES OF DATA ON COUNTIES

Source	Type of data contributed
County and City Data Book 1972(39)	Demographic, business, agricultural
1969 Census of Agriculture(40)	Agricultural equipment populations (1969)
Area Measurement Reports(41)	Land and water areas (1960)
New York State Statistical Yearbook - 1973(7)	Outboard and snowmobile registration data
Statistical Abstract of Ohio - 1969(8)	Outboard registration data
South Carolina Statistical Abstract - 1973(9)	Outboard registration data
Wisconsin Statistical Abstract - Third Edition - June 1974(10)	Outboard registration data
Secretary of State, State of Illinois(42)a	Motorcycle registration data
Missouri Department of Revenue(43)	Motorcycle and outboard registration data

[a] Two examples of sources for motorcycle registration data - the other states were not contacted.

with descriptions of the types of data obtained. In some cases, of course, the data contributed by a given source to this project constitute only a small portion of the data available from that source; and there may be a great many more sources (e.g., state motor vehicle departments) which provide equally useful data.

A number of other sources contain a lesser amount of data for counties, and these sources are listed (along with those given in Table 19) in Appendix B. Another source of county data useful to this effort has been county maps of the type prepared and distributed by state highway departments. These maps normally include not only roads but also bodies of water, boundaries and populations of incorporated places, rural dwellings, and many other features. The maps used during this project were on a scale of one-half inch equals one mile (1:126,720), but larger-scale maps are usually available and should be used for any serious effort at making county and grid emissions estimates.

IV. METHODOLOGY FOR COUNTY EMISSIONS ESTIMATES

Availability of data and the applicability of specific items and techniques varies among the emissions sources being considered here, so each source will be considered in a separate subsection. Before arriving at the methodologies presented, experimentation was conducted with a number of alternatives for some of the source categories. Documentation of this research is provided in Appendix C, although the methods presented in the text are recommended as preferable overall.

A. OUTBOARD MOTORS

As a consequence of the Federal Safety Act of 1971, most states are currently registering all power boats operating within their borders; but a few states still exempt very small craft (common exemption limit is under 10 horsepower). Statistics for 1974 (available in 1975) should have registrations for all power boats, since the exemptions are no longer approved by the Coast Guard after calendar year 1973. A number of states tabulate boat registrations by county as well as total for the state, but county tabulations are not required for Coast Guard approval.

For the states in which boat registrations are available by county, the county boat population will be assumed to equal registrations plus any applicable correction for boats not registered. It would be worth expending considerable effort to find boat registrations by county or to extract such values from available data, because registrations by county are not easily projected from other generally-available county data.

Data from four states (New York(7), Ohio(8), South Carolina(9), and Wisconsin(10)) confirm that boat registrations correlate strongly with population on a county basis. Simple regression analysis shows correlation coefficients r^2 from 0.70 to 0.99 for individual states, and around 0.75 for the four states taken together. New York data(7) also show that, except for inland counties having no surface water usable for boating ("dry" counties), boats used correlate strongly with boats registered (r^2 over 0.9). To be recorded by the Bureau of the Census(41), ponds must be at least 40 acres (0.16 km^2) in area and streams must be at least 1/8 mile (0.20 km) wide. The best estimate of boats used in a county, therefore, is to apportion total state boat registrations (corrected for boats not registered, if any) by population. Adjustments for individual inland counties can be made if no inland water usable for boating exists by simply neglecting outboard emissions. Care should be exercised, however, to make certain that a given county really has no water usable for boating; because many reservoirs have been constructed since these area measurements were made (1960 or earlier). A correction for disproportionately low registrations and usage in densely populated counties can also be made according to the empirical relationship (based on four-state data(7-10)

$$\text{percent of state boat total used in county} = 31.6\,(\text{population density, inhabitants/mi}^2)^{-0.5} \times (\text{percent of state population in county})$$

for counties having population densities over 1000 inhabitants/mi^2.

The general equation to be used for outboard emissions is

$$\text{county emissions (kg/yr)} = (\text{boats used in county}) \times (\text{emission factor, kg/unit year}).$$

The emission factor is a function of the mixture of boats in the boat population (sizes and types) as well as annual operating time. Although it would be desirable to use a specific mixture of boat sizes and types for each county, such data are not available; so it will be necessary to assume a "typical" mixture(3) in order to proceed with calculations.

Annual boat usage has been estimated to average 75 hours nationwide(3), but usage undoubtedly varies with climatic conditions. For the purposes of this methodology, annual usage will be estimated by the equation

$$\text{annual boat usage (hr)} = 10C_2;$$

where C_2 = number of months during which "monthly normal" temperature exceeds:

45°F for counties in the north region (43°N latitude and northward)
48°F for counties in the central region (37°N latitude to 43°N latitude)
55°F for counties in the south region (south of 37°N latitude).

The temperatures were computed by assuming that the annual period of usage averages six months in the north region, seven months in the central region, and eight months in the south region. "Monthly normal" temperatures are averages of daytime highs and lows averaged over each month of the year for a long period of time (typically 30 years or more). Such data are usually compiled for all weather stations, and data for the nearest weather station can be used. The expression for the yearly average emission factor thus becomes

$$\text{emissions in kg/unit yr} = 0.01\ C_2\ (\text{emissions in g/unit hr}).$$

It is understood that the emissions under consideration are air pollutants only, so the factors should not include pollutants expected to remain in the water phase.

B. SNOWMOBILES

Snowmobiles are used mainly in the north central and northeast states, and good state registration data are available(11). Registrations by county, however, were found only for New York(7); and they correlate very well with snowmobiles used in each county (r^2 over 0.99). In order to predict usage of snowmobiles by county where county data are not available, urban and non-urban counties should be separated. For non-urban counties in New York (population density under 1000 inhabitants per square mile), multiple regression analysis yielded the following relationship ($r^2 = 0.66$):

$$\begin{aligned}\text{percent of state snowmobiles used in county} = {} & -2.345 + {}\\ & 1.560\ (\text{percent of state population in county}) + {}\\ & 0.0325\ (\text{percent snowfall at state geographic center}).\end{aligned}$$

Other variables with which experimentation was conducted, such as number of developed trails and number of large farms, exhibited very weak correlation with snowmobile usage. The percentages resulting from the equation above can be used with state snowmobile registrations to compute the number of snowmobiles operating in each county.

For urban areas where population density is 1000 inhabitants per square mile or more, snowmobile usage decreases as a function of population density. It appears that usage drops to zero when population density reaches about 3000 per square mile, so it will be assumed that usage in urban areas follows the relationship

$$\begin{aligned}&\text{percent of state snowmobiles used in county} =\\ &C_4\left[1.5 - 0.0005\,(\text{county population density, inhabitants/mi}^2)\right] \times\\ &\qquad (\text{percent of state population in county}),\end{aligned}$$

where $C_4 = 1$ for densities from 1000 to 3000 per square mile and $C_4 = 0$ for densities above 3000 per square mile.

The general equation used to estimate snowmobile emissions on a county basis is

$$\text{county emissions (kg/yr)} = \text{(total national emissions, kg/yr)}\ \frac{\text{(snowmobiles operating in county)}}{\text{(national snowmobile registrations)}}.$$

C. MOTORCYCLES

The methodology for motorcycles is one of the least complicated of those under consideration, because registration data for motorcycles are available by county. Registrations only tell part of the story, however, since some motorcycles are always unregistered in each part of the country. The general relationship to be used for motorcycle emissions is

$$\text{county emissions (kg/yr)} = \left[\text{(county registrations) / (1 - fraction units unregistered)}\right] \times \text{(emission factor, kg/unit yr)}.$$

The county registration data are available from individual state motor vehicle departments, and the fraction of units unregistered is available on both national and regional bases from a recent statistical survey(19). The emission factor for the population of motorcycles under consideration is computed for each pollutant by

$$\text{factor, kg/unit yr} = (0.001) \sum_{i=i}^{8} F_i \left[\left(\text{emissions, g/mi} \times \frac{\text{mi}}{\text{yr}}\right) + C_1 \left(\text{riding season, days}\right) \left(\text{tank volume}, \ell\right) \left(\frac{0.53\ \text{g HC}}{\ell\ \text{tank volume day}}\right)\right]_i,$$

where i = individual motorcycle type/size (e.g., 2-stroke, 91-190 cm^3 displacement)

F_i = fraction of motorcycle population under consideration which is classified in category i

C_1 = 1.0 for hydrocarbons, 0.0 for other pollutants.

The factors F_i and distances travelled annually are available from the same statistical survey mentioned above(19) on both national and regional bases. Length of the riding season in days is available as a national average from another survey(20), and a method has been devised to correct the riding season for specific locations by making use of monthly normal temperatures for U.S. Cities(44). This correction simply involves counting the number of months during which monthly normal temperature was 38°F or higher for the location of interest and converting those months to days. Fuel tank volumes can be estimated at 2.0 gallons (7.6 ℓ) for bikes of 90 cc or less, 2.5 gallons (9.5 ℓ) for those in the 91-190 cc range, 3.0 gallons (11.4 ℓ) for those in the 191-290 cc range, and 3.5 gallons (15.2 ℓ) for those over 290 cc.

D. LAWN AND GARDEN EQUIPMENT

Emissions from individual small utility engines of the types used in lawn and garden equipment have been studied thoroughly(32, 30), and estimates of national emissions have been made using these emissions results as basis(32, 31). To allocate emissions from lawn and garden equipment by county, however, consideration will be given to areas where these machines are used and to seasonal factors. Lawn and garden equipment is used predominantly around homes, so it seems reasonable that equipment population should correlate well with number of one-unit housing structures(39). This data item will be the basic criterion by which emissions from lawn and garden engines are allocated to counties.

An additional factor for lawn and garden equipment is the highly seasonal nature of its use. Data on occurrence of freezing conditions(17) can be used to predict the length of season for use of mowers, edgers, and tillers. Usage of snowthrowers is predominantly limited to relatively few states, where snowfalls of one inch or more are recorded 10 or 15 times per year (or more frequently). This usage can be evaluated by assuming that no snowthrowers are in service where annual snowfall is under 30 inches and that each snowthrower operates eight minutes for each inch of snowfall. These assumptions are based on a "typical" snowfall of 2.5 inches and a typical usage time of 20 minutes per snowfall. The criterion of 30 inches annual snowfall leads to an (approximate) dividing line of 40°N latitude separating the region of snowthrower operation from generally warmer climates. The distribution of snowthrowers will be assumed to follow the distribution of population in those areas where they are likely to be in service.

The general relationship for lawn and garden equipment emissions is

$$\begin{aligned}
&\text{county emissions (kg/yr)} = \text{(nat'l emissions except snowthrowers, kg/yr)} \times \\
&\left(\frac{\text{average operating year}}{\text{213 days}}\right)\left(\frac{\text{county mean freeze-free days}}{\text{year}}\right) \times \\
&\left(\frac{\text{county one-unit housing structures}}{\text{national one-unit housing structures}}\right) + C_3\left(\frac{\text{county population}}{\text{heavy snow zone population}}\right) \times \\
&\text{(national snowthrower population)}\left(\frac{\text{one hour operation}}{\text{7.5 inches snowfall}}\right) \times \\
&\text{(county snowfall, in/yr) (emission factor, kg/hr);}
\end{aligned}$$

where $C_3 = 0$ for counties having less than 30 inches annual snowfall,and
$C_3 = 1$ for counties having 30 inches annual snowfall or more.

The "heavy snow zone population" is the sum of populations of 19 states plus half the populations of three additional states, totalling 83.98 million (1970 census). County snowfall can be assumed equal to that recorded at the nearest reporting station, either inside or outside the county.

E. CONSTRUCTION EQUIPMENT

Nationwide emissions from construction equipment have been estimated by several individual efforts(34, 35, 36), and there is reasonably good agreement on the totals. Allocation of these emissions will be made first to the states, based on construction dollar volume(45). Allocation to counties will then be made by population.

The construction volume data to be used are available at intervals of six months in the open literature and probably at smaller intervals by consulting directly with the source. The data are broken into three major categories: heavy construction, highways and bridges, and building construction (not including homebuilding). The first two categories make use of more engine-powered equipment per dollar of construction performed than building construction does, so construction dollars in the first two categories will be weighted by a factor of 3 as compared to those spent in building construction. The relationship used to calculate county emissions from construction equipment (based on the above considerations) is

$$\text{county emissions (kg/yr)} = \text{(national emissions, kg/yr)} \frac{\text{(state const. volume) (county population)}}{\text{(nat'l const. volume) (state population)}} .$$

Emissions due to homebuilding and other light construction are considered negligible compared to emissions from larger (contracted) construction jobs.

F. INDUSTRIAL EQUIPMENT

Based on rather minimal information, emissions from industrial engines have been estimated on a national basis(34). This category includes engine applications such as: fork-lifts, generators, pumps, and other machinery used by manufacturing concerns; refrigeration units, auxillary engines, and material-handling machinery used in wholesale trade; and machinery used in mining and quarrying. The method used in this case will be to apportion emissions to counties directly from national estimates by the relationship

$$\text{county emissions(kg/yr)} = (\text{national emissions kg/yr}) \frac{\text{county }(A + B + C)}{\text{national }(A + B + C)};$$

where A = value added by manufacturing establishments,
B = sales of wholesale trade establishments, and
C = value of shipments and receipts of mineral industries.

In some cases it will be necessary to estimate these quantities by apportioning state data according to number of establishments of each type in the county. Such estimation will be necessary to a greater extent for item "C" than for the others, but it is (for most counties) a relatively small contributor to the sum of A, B, and C.

G. FARM EQUIPMENT

Emissions from motorized farm equipment can be estimated quite accurately due to availability of good data on machine populations(40) and well-documented estimates of annual machine usage(34, 37, 38, 32). Population data are available for farm tractors, garden tractors used on farms, combines, motorized balers, and motorized forage harvesters. Population estimates for large miscellaneous engines (mostly used in irrigation), small utility engines, and small utility engines used specifically on lawn and garden equipment can also be made.

The large (mostly water-cooled) general purpose engines in service nationwide number about 27 percent of the tractor population(46). It will be assumed that these engines number 5 percent of the tractor population in non-irrigated areas and 30 percent in irrigated areas. General-purpose small utility engines (used on augers, sprayers, etc.) will be assumed to number 1.5 per farm (class 1-5 farms only). These assumptions are based on the ratio of engines in service in agriculture nationwide to total number of farms and consideration of typical farm requirements. Annual usage of all these items of equipment and applicable emission factors have been developed sufficiently for use in this methodology.

The basic relationship for calculating emissions from farm equipment is

$$\text{county emissions (kg/yr)} = \sum(\text{equipment population}) \times (\text{annual usage})(\text{emission factor, kg/hr}),$$

where the summation is taken over the types of equipment used.

The number of class 1-5 farms in each county is also available from the Census of Agriculture(40), along with specific data on machinery populations.

V. DEMONSTRATION OF COUNTY EMISSIONS ESTIMATION METHODOLOGIES

The methodologies presented in Section IV are demonstrated in this section for the 12 counties in the St. Louis Metropolitan Air Quality Control Region (AQCR 070). While most aspects of the methodologies can be demonstrated well for these particular counties, special situations restricting applicability or accuracy will be identified. It should be noted, however, that unforeseen circumstances are very likely to occur if the methodologies are applied widely in the field, creating a need for sound judgment and good knowledge of the area under study.

A. OUTBOARD MOTORS

Referring back to Section IV.A., certain data are needed for each county to compute the emissions impact of outboard motors. These data are summarized in Table 20 for the counties in AQCR 070. Before the Missouri outboard registration data can be used, they must be multiplied by the appropriate correction factor from Table 1 (1.48) to account for unregistered small craft. To convey an idea of the accuracy of the registration data under discussion, the Missouri total (corrected for unregistered units) is 227,450 motors as determined by the Department of Revenue, while other sources show 196,000 motors(2) and 105,013 outboard boats(3). It is likely that the last figure is low due to non-inclusion of small boats (it would correct to 155,419), but there is still a considerable amount of disagreement. The figure considered most reasonable for outboard boats in Illinois is listed in Table A-1 of Appendix A, and for the end of 1973 this figure is 182,120.

The value of C_2 listed in Table 20 is seven (months), so annual boat usage for AQCR 070 is estimated at $10C_2 = 70$ hours. The formula for annual emissions becomes

emissions in kg/unit yr = 0.07 (emissions in g/unit hr).

Table 20. COUNTY DATA TO BE USED IN DETERMINING OUTBOARD MOTOR EMISSIONS IMPACT

State	County	Outboard regist.	% state popul.	Population density, inhab. / mi^2	Inland water, mi^2	C_2
Illinois	Bond	------[a]	0.126	37	3.0[c]	7
	Clinton	------	0.255	65	38.4[d]	7
	Madison	------	2.26	342	12.5	7
	Monroe	------	0.170	49	9.1	7
	Randolph	------	0.282	53	12.2	7
	St. Clair	------	2.57	424	2.2	7
	Washington	------	0.124	24	0.6	7
Missouri	Franklin	2,536[b]	1.18	59	8.3	7
	Jefferson	5,108[b]	2.25	158	3.4	7
	St. Charles	4,468[b]	1.99	169	35.0	7
	St. Louis	23,488[b]	20.3	1,907	17.6	7
	St. Louis City	12,121[b]	13.3	10,201	3.8	7

[a] Not available for Illinois.

[b] Includes only boats with motors of 7.5 hp or more.

[c] Shown on county road map - 0.0 mi^2 in 1960 tabulation(41).

[d] Shown on county road map - only 0.1 mi^2 in 1960 tabulation(41).

Based on 1973 Illinois total boat registrations apportioned according to population and corrected Missouri registrations by county, Table 21 shows county emissions and fuel consumption of outboard motors using factors from Table 2. These values will be combined later with emissions from the other categories of interest to determine totals for counties and AQCR 070. In terms of season, the outboard emissions are expected to occur during the months of April through October, inclusive.

B. SNOWMOBILES

As shown by data in Table A-3 of Appendix A, no snowmobiles are registered in Missouri; and 34,500 are registered in Illinois. Using the method developed in Section IV.B. for apportioning the snowmobile population to counties, the equation for Illinois counties becomes

$$\begin{aligned} \text{snowmobiles in county} &= -809. + 538. \ (\text{\% of state popul. in county}) \\ &\quad + 11.1 \ (77.7) \\ &= 53 + 538 \ (\text{\% of state popul. in county}) \end{aligned}$$

assuming that average snowfall at the state geographic center is 22.0 inches per year. All emissions from snowmobiles, of course, would

Table 21. EMISSIONS AND FUEL CONSUMPTION OF OUTBOARD MOTORS FOR COUNTIES IN AQCR 070

State	County	Outboard boats used	Emissions, 10^3 kg/yr					Fuel used, 10^3 gal/yr
			HC	CO	CO_2	NO_x	SO_x	
Illinois	Bond	229	12.3	36.5	56.3	0.072	0.071	24.5
	Clinton	464	25.0	74.1	114.	0.146	0.143	49.7
	Madison	4,116	222.	657.	1,010.	1.30	1.27	441.
	Monroe	310	16.7	49.5	76.2	0.098	0.096	33.2
	Randolph	514	27.7	82.0	126.	0.162	0.158	55.0
	St. Clair	4,680	252.	747.	1,150.	1.47	1.44	501.
	Washington	226	12.2	36.1	55.5	0.071	0.070	24.2
Missouri	Franklin	3,753	12.2	36.1	55.5	0.071	0.070	402.
	Jefferson	7,560	407.	1,210.	1,860.	2.38	2.33	810.
	St. Charles	6,613	356.	1,060.	1,620.	2.08	2.04	708.
	St. Louis	34,762	1,870.	5,550.	8,540.	11.0	10.7	3,720.
	St. Louis City	17,939	966.	2,860.	4,410.	5.65	5.53	1,920.
Total AQCR 070		81,166	4,370.	13,000.	19,900.	25.6	25.0	8,690.

occur in the winter months (December through March, in this case). Snowmobile populations, emissions, and fuel consumption are summarized in Table 22 for the counties of AQCR 070 where they are computed to occur. It is probable that the error of estimate in this case makes these values higher than actual, due to the rather minimal snowfall in the area for lengthy snowmobile operation.

C. MOTORCYCLES

Emissions from motorcycles are estimated using the method in Section IV. C. and data from Section II. C. The breakdown according to engine size and type is taken from Table 6, and the riding season is computed to be nine months (March through November) or 275 days. The computation of emission factors (in kg/unit year) and fuel consumption is outlined in Table 23, with the results for AQCR 070 appearing as "weighted composites" at the bottom of the table.

Table 23. COMPUTATION OF EMISSION FACTORS AND FUEL CONSUMPTION FOR MOTORCYCLES IN AQCR 070

Motorcycle size	i	Fi	Emissions in kg/unit year						Fuel usage, gal/yr
			HC	CO	NO_x	Part.	RCHO	SO_x	
4-s/0-90cc	1	0.109	2.7	15.	0.16	0.016	0.014	0.010	8.5
4-s/91-190cc	2	0.127	5.0	34.	0.28	0.042	0.036	0.024	19.
4-s/191-290cc	3	0.058	8.8	67.	0.36	0.094	0.092	0.046	38.
4-s/over 290cc	4	0.231	16.	140.	0.33	0.21	0.24	0.093	75.
2-s/0-90cc	5	0.098	5.6	4.5	0.082	0.10	0.075	0.016	9.4
2-s/91-190cc	6	0.115	15.	17.	0.14	0.27	0.15	0.035	20.
2-s/191-290cc	7	0.053	40.	63.	0.08	0.74	0.27	0.090	52.
2-s/over 290cc	8	0.208	77.	150.	0.12	1.65	0.42	0.17	100.
Weighted composite			26.	79.	0.20	0.50	0.19	0.074	50.

Calculation of emissions by county requires registration data, which are available(42, 43), and an assumption of the percentage of unregistered motorcycles in the total population (15 percent for AQCR 070)(19). Emissions and fuel consumption for counties are shown in Table 24, as well as a total for AQCR 070. As already mentioned, these emissions would occur during the March through November period; and they appear to be concentrated in the more urban counties.

D. LAWN AND GARDEN EQUIPMENT

This category is divided into two classes, namely snowthrowers and other equipment. According to criteria suggested in Section IV. D.,

Table 22. SNOWMOBILE EMISSIONS AND FUEL CONSUMPTION, COUNTIES IN AQCR 070

State	County	Snowmobiles in use	Emissions, 10^3 kg/yr						Fuel used, 10^3 gal/yr
			HC	CO	NO_x	Part.	RCHO	SO_x	
Illinois	Bond	121	4.57	7.10	0.073	0.202	0.067	0.006	6.78
	Clinton	190	7.18	11.2	0.114	0.317	0.10	0.010	10.6
	Madison	1269	48.0	74.5	0.761	2.12	0.70	0.065	71.1
	Monroe	144	5.44	8.45	0.086	0.240	0.079	0.007	8.06
	Randolph	205	7.75	12.0	0.123	0.342	0.11	0.010	11.5
	St. Clair	1436	54.3	84.3	0.862	2.40	0.79	0.073	80.4
	Washington	120	4.54	7.04	0.072	0.200	0.066	0.006	6.72
Total AQCR 070		3485	132.	205.	2.09	1.9	5.82	0.178	195.

Table 24. EMISSIONS AND FUEL CONSUMPTION OF MOTORCYCLES, COUNTIES IN AQCR 070

State	County	Motorcycles[a] in use	Emissions, 10^3 kg/yr						Fuel used, 10^3 gal/yr
			HC	CO	NO_x	Part.	RCHO	SO_x	
Illinois	Bond	555	14	44	0.11	0.28	0.11	0.04	28.
	Clinton	713	19	56	0.14	0.36	0.14	0.05	36.
	Madison	6,080	160	480	1.2	3.0	1.2	0.45	300.
	Monroe	500	13	40	0.10	0.25	0.10	0.04	25.
	Randolph	1,012	26	80	0.20	0.51	0.19	0.07	51.
	St. Clair	4,969	130	390	0.99	2.5	0.94	0.37	250.
	Washington	295	8	23	0.06	0.15	0.06	0.02	15.
Missouri	Franklin	1,608	42	130	0.32	0.80	0.31	0.12	80.
	Jefferson	3,320	86	260	0.66	1.7	0.63	0.25	170.
	St. Charles	3,492	91	280	0.70	1.7	0.66	0.26	170.
	St. Louis	14,392	370	1,100	2.9	7.2	2.7	1.1	720.
	St. Louis City	10,084	260	800	2.0	5.0	1.9	0.75	500.
Total AQCR 070		47,020	1,200	3,700	9.4	24.	8.9	3.5	2,400.

[a] Assuming 15 percent of motorcycles unregistered(19)

only an insignificant number of snowthrowers should be operating in the St. Louis area; so they will be omitted from this analysis. National emissions and fuel consumption of equipment other than snowthrowers are computed using data from Tables 10 and 12, assuming 2.7 million 2-stroke engines and 50.2 million 4-stroke engines. The other data required for this computation are the mean freeze-free days per year (205)(17) and the numbers of one-unit housing structures in the individual counties and the nation(39). The number of one-unit housing structures in the nation is approximately 46.8 million, and emissions apportioned to counties using this variable are shown in Table 25 along with fuel consumption and calculated county engine populations. Emissions from lawn and garden equipment occurring in AQCR 070 are about 1 percent of the national total emissions from this engine category.

E. CONSTRUCTION EQUIPMENT

Emissions from construction equipment are given in Table 14 (along with fuel consumption) as national totals, and the construction dollar volume data required for apportioning the national totals to states can be obtained from Reference 29 (August 1974 issue in this case). Computation of the percentage of national construction equipment emissions allocated to the two states within which AQCR 070 falls (Illinois and Missouri) is presented in Table 26. These percentages are equal to the weighted averages of construction dollar percentages given in the last column of Table 26.

Table 26. COMPUTATION OF ILLINOIS AND MISSOURI CONSTRUCTION EQUIPMENT EMISSIONS AS PERCENTAGES OF NATIONAL TOTALS

Area or state	Heavy const.		Highway const.		Building const.[a]		Avg.[b]
	10^6 dol.	%	10^6 dol.	%	10^6 dol.	%	%
U.S.[c]	11,140	100	4,385	100	13,097	100	100
Illinois	395	3.55	297	6.77	834	6.37	5.33
Missouri	214	1.92	148	3.38	348	2.66	2.65

[a] Excluding homebuilding.
[b] Weighted using method in Section IV.E.
[c] Excluding Alaska and Hawaii.

The state percentages can be divided further to make county estimates by apportioning according to population. Percentages of state populations for each county in AQCR 070 were given in Table 20, and they are used with percentages from Table 26 and national totals from

Table 25. LAWN AND GARDEN ENGINE EMISSIONS AND FUEL CONSUMPTION FOR COUNTIES IN AQCR 070

State	County	One-unit housing structures	Computed engine populations		Fuel used 10^3 gal/yr
			4-stroke	2-stroke	
Illinois	Bond	4,490	4,820	259	53.4
	Clinton	7,788	8,350	449	92.5
	Madison	65,533	70,300	3,780	779.
	Monroe	5,383	5,770	311	63.9
	Randolph	8,624	9,250	498	102.
	St. Clair	68,769	73,800	3,970	817.
	Washington	4,848	5,200	280	57.6
Missouri	Franklin	15,882	17,000	916	188.
	Jefferson	27,593	29,600	1,590	328.
	St. Charles	21,631	23,200	1,250	257.
	St. Louis	235,303	252,000	13,600	2790.
	St. Louis City	81,784	87,700	4,720	971.
Total AQCR 070		547,628	587,000	31,600	11,750.

State	County	Emissions, 10^3 kg/yr					
		HC	CO	NO_x	Part.	RCHO	SO_x
Illinois	Bond	12.6	100.	1.01	0.27	0.23	0.11
	Clinton	21.8	174.	1.76	0.46	0.40	0.19
	Madison	183.	1,460.	14.8	3.89	3.3	1.56
	Monroe	15.1	120.	1.22	0.32	0.27	0.13
	Randolph	24.1	192.	1.95	0.51	0.44	0.20
	St. Charles	192.	1,530.	15.5	4.08	3.5	1.63
	Washington	13.6	108.	1.09	0.29	0.25	0.12
Missouri	Franklin	44.4	354.	3.59	0.94	0.81	0.38
	Jefferson	77.1	615.	6.23	1.64	1.4	0.66
	St. Charles	60.5	482.	4.88	1.28	1.1	0.51
	St. Louis	658.	5,240.	53.1	14.0	12.	5.59
	St. Louis City	229.	1,820.	18.5	4.85	4.2	1.94
Total AQCR 070		1,530.	12,200.	124.	32.5	28.	13.0

Table 14 to compute county emissions as shown in Table 27. As expected, this category has a much larger fuel consumption and loading of NO_x emissions than any of the others examined thus far.

F. INDUSTRIAL EQUIPMENT

Fuel consumption and emissions of industrial engines are given in Table 16 as national totals, and information required to apportion emissions according to the method outlined in Section IV.F. is presented in Reference 39. These latter data are summarized in Table 28 for the counties in AQCR 070, indicating that a range from about 0.002 percent to 0.8 percent of national industrial engine emissions occur within individual counties. Using national emissions and fuel consumption data from Table 16 in conjunction with percentage distributions from Table 28, industrial engine emissions by county for AQCR 070 have been calculated and appear as Table 29. The population of industrial engines is more heavily weighted toward gasoline-fueled units than the population of construction equipment, so it produces more HC and CO and less NO_x than does construction equipment on a specific basis.

Table 28. COMPUTATION OF INDUSTRIAL EQUIPMENT POPULATION PERCENTAGES FOR COUNTIES IN AQCR 070

Area or state	County	Millions of dollars			$\left(\frac{\text{County A+B+C}}{\text{U.S. A+B+C}}\right)$
		A = value added	B = wholesale sales	C = minerals	
U.S.	All	261,983.8	459,475.967	25,848.7	1.0
Illinois	Bond	13.2	14.583	-------[a]	3.72x10^{-5}
	Clinton	17.1	17.391	-------[a]	4.62x10^{-5}
	Madison	645.2	229.629	2.8	1.17x10^{-3}
	Monroe	0.9	12.829	-------[a]	1.84x10^{-5}
	Randolph	30.3	14.394	18.4	8.44x10^{-5}
	St. Clair	267.3	519.297	-------[a]	1.05x10^{-3}
	Washington	2.3	15.643	2.8	2.78x10^{-5}
Missouri	Franklin	56.0	25.699	-------[a]	3.44x10^{-5}
	Jefferson	66.4	17.333	3.0	1.12x10^{-4}
	St. Charles	44.8	33.644	-------[a]	1.05x10^{-4}
	St. Louis	1,285.8	3,065.356	9.8	5.84x10^{-3}
	St. Louis City	1,793.5	4,518.156	0.7	8.45x10^{-3}
Total AQCR 070		4,222.8	8,483.954	37.5	1.71x10^{-2}

[a] Negligible

Table 27. CONSTRUCTION EQUIPMENT EMISSIONS AND FUEL CONSUMPTION FOR COUNTIES IN AQCR 070

State	County	% national emissions	Emissions, 10^3kg/yr						Fuel used, 10^3gal/yr[a]
			HC	CO	NO_x	Part.	RCHO	SO_x	
Illinois	Bond	0.00672	8.60	88.7	57.5	4.38	1.2	4.48	351.
	Clinton	0.0136	17.4	180.	116.	8.87	2.4	9.06	710.
	Madison	0.120	154.	1,580.	1,030.	78.2	22.	79.9	6,260.
	Monroe	0.00906	11.6	120.	77.6	5.91	1.6	6.03	473.
	Randolph	0.0150	19.2	198.	128.	9.78	2.7	9.99	783.
	St. Clair	0.137	175.	1,810.	1,170.	89.3	25.	91.2	7,150.
	Washington	0.00661	8.46	87.3	56.6	4.31	1.2	4.40	345.
Missouri	Franklin	0.0313	40.1	413.	268.	20.4	5.6	20.8	1,630.
	Jefferson	0.0596	76.3	787.	510.	38.9	11.	39.7	3,110.
	St. Charles	0.0527	67.5	696.	451.	34.4	9.5	35.1	2,750.
	St. Louis	0.538	689.	7,100.	4,610.	351.	97.	358.	28,100.
	St. Louis City	0.352	451.	4,650.	3,010.	230.	63.	234.	18,400.
Total AQCR 070		1.342	1,720.	17,700.	11,500.	875.	240.	894.	70,000.

[a] 88.5 percent of gallons are diesel fuel, 11.5 percent gasoline.

Table 29. INDUSTRIAL ENGINE EMISSIONS AND FUEL CONSUMPTION FOR COUNTIES IN AQCR 070

State	County	Emissions, 10^3 kg/yr						Fuel used, 10^3 gal/yr[a]
		HC	CO	NO_x	Part.	RCHO	SO_x	
Illinois	Bond	4.60	73.3	10.3	0.72	0.2	0.66	79.6
	Clinton	5.71	91.0	12.8	0.90	0.3	0.82	98.9
	Madison	145.	2,300.	323.	22.7	6.7	20.8	2,504.
	Monroe	2.28	36.2	5.1	0.36	0.1	0.33	39.4
	Randolph	10.4	166.	23.3	1.64	0.5	1.50	181.
	St. Clair	130.	2,070.	290.	20.4	6.0	18.6	2,250.
	Washington	3.44	54.7	7.7	0.54	0.2	0.49	59.5
Missouri	Franklin	4.26	67.7	9.5	0.67	0.2	0.61	73.7
	Jefferson	13.9	221.	30.9	2.17	0.6	1.99	240.
	St. Charles	13.0	207.	30.0	2.04	0.6	1.86	225.
	St. Louis	722.	11,500.	1,610.	113.	33.	104.	12,500.
	St. Louis City	1,050.	16,600.	2,330.	164.	48.	150.	18,100.
Total AQCR 070		2,120.	33,700.	4,720.	332.	96.	304.	36,600.

[a] 49.8 percent of gallons are diesel fuel, 50.2 percent gasoline.

G. FARM EQUIPMENT

To compute emissions and fuel consumption of farm equipment by county, data from Reference 40 on equipment populations are used with information from Tables 17 and 18 on annual equipment usage and emission rates. To simplify the calculations, composite emission and fuel consumption factors can be used for all tractors (both gasoline and diesel). These factors (in kg/hr) are 0.153 HC, 1.71 CO, 0.259 NO_x, 0.030 Particulate, 0.011 RCHO, 0.020 SO_x, and 6.77 fuel. In addition, the composite annual tractor usage is 352 hours and fuel used in tractors is 53.1 percent diesel fuel by volume. A similar analysis for combines yields factors (in kg/hr) of 0.281 HC, 6.00 CO, 0.372 NO_x, 0.049 Particulate, 0.014 RCHO, 0.031 SO_x, and 14.1 fuel. Composite annual combine usage is 70 hours, and fuel used in combines is 34.2 percent diesel fuel by volume. Looking at the other farm application made up of both diesel and gasoline engines, fuel used in miscellaneous heavy-duty engines is 35.4 percent diesel fuel by volume.

Equipment populations for the counties in AQCR 070 (1969) are listed in Table 30 along with totals for the region. These data can be used with emission and fuel consumption factors given above in the text and in Table 18 to calculate total emissions by county. To avoid

Table 30. FARM EQUIPMENT POPULATIONS FOR COUNTIES IN AQCR 070[(40)]

State	County	Population by type of equipment (1969)					
		Tractors	Combines	Balers	Forage harv.	Misc. heavy duty	Misc. light duty
Illinois	Bond	1,967	379	291	104	98	1,140
	Clinton	2,946	527	586	303	147	1,602
	Madison	4,513	782	751	157	226	2,234
	Monroe	2,244	454	256	72	112	1,068
	Randolph	2,948	484	537	151	147	1,480
	St. Clair	3,746	785	478	141	187	1,878
	Washington	2,980	674	509	185	149	1,580
Missouri	Franklin	3,128	190	726	149	156	1,400
	Jefferson	1,312	91	382	49	66	514
	St. Charles	2,700	472	358	93	135	1,242
	St. Louis	1,179	154	125	16	59	554
	St. Louis City	------	-----	-----	-----	-----	------
Total AQCR 070		29,663	4,992	4,999	1,420	1,482	12,692

Table 31. FARM EQUIPMENT EMISSIONS AND FUEL CONSUMPTION FOR COUNTIES IN AQCR 070

State	County	Emissions, 10^3 kg/yr						Fuel used[a]
		HC	CO	NO_x	Part.	RCHO	SO_x	10^3 gal/yr
Illinois	Bond	118.	1,410.	199.	23.7	8.4	15.6	1,770.
	Clinton	179.	2,110.	309.	37.3	13.	24.5	2,730.
	Madison	268.	3,190.	448.	53.0	19.	35.0	3,980.
	Monroe	134.	1,600.	224.	26.5	9.5	17.5	1,990.
	Randolph	175.	2,080.	296.	35.2	12.	23.2	2,620.
	St. Clair	225.	2,690.	376.	44.6	16.	29.4	3,350.
	Washington	181.	2,180.	306.	36.6	13.	24.1	2,730.
Missouri	Franklin	180.	2,080.	305.	36.1	13.	23.8	2,690.
	Jefferson	75.8	885.	127.	15.0	5.4	9.9	1,130.
	St. Charles	160.	1,900.	268.	31.7	11.	20.9	2,380.
	St. Louis	68.3	803.	114.	13.3	4.8	8.8	1,010.
	St. Louis City	-------	-------	------	-----	-----	-----	-------
Total AQCR 070		1,760.	20,900.	2,970.	353.	120.	233.	26,400.

[a] 52.5 percent of gallons are diesel fuel, 47.5 percent gasoline.

unnecessary complication, the results of this calculation are given in Table 31 as totals for all the farm equipment in each county rather than as totals for each type of equipment. In the computations for farm equipment emissions and fuel consumption, it is necessary to assume that the diesel and gasoline population fractions are the same as for the national population. Although this assumption may be somewhat in error for specific counties, no data are available at the county level which would permit a more refined analysis.

Having calculated emissions and fuel consumption for the seven categories of internal combustion engines under study, it is now possible to construct a summary which can be compared to the NEDS (National Emissions Data System) survey data for AQCR 070. This summary is presented in Table 32 with the NEDS data for off-highway gasoline- and diesel-powered vehicles and a total for the AQCR.

Table 32. SUMMARY OF EMISSIONS FROM ENGINE CATEGORIES UNDER STUDY

Category	Emissions, 10^3 kg/yr					
	HC	CO	NO_x	Part.	RCHO	SO_x
Outboard motors	4,370.	13,000.	25.6	-------	-----	25.0
Snowmobiles	132.	205.	2.1	5.8	1.9	0.2
Motorcycles[a]	1,200.	3,700.	9.4	24.	8.9	3.5
Lawn and garden	1,530.	12,200.	124.	32.5	28.	13.0
Construction	1,720.	17,700.	11,500.	875.	240.	849.
Industrial	2,120.	33,700.	4,720.	332.	96.	304.
Farm	1,760.	20,900.	2,970.	353.	120.	233.
Total	12,800.	101,000.	19,400.	1,620.	490.	1,430.
NEDS gasoline[b]	4,050.	22,200.	1,290.	59.	-----	36.
NEDS diesel[b]	337.	2,050.	3,370.	118.	-----	246.
NEDS total[b]	4,390.	24,200.	4,660.	177.	-----	282.

[a] 25 percent of this total estimated off-highway.

[b] Off-highway I.C. engine area sources.

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VI. METHODOLOGY FOR GRID ELEMENT EMISSIONS ESTIMATES

The intrinsic properties of grid elements which can be helpful in making emissions estimates for them include:

1. area (1, 4, 25, or 100 km^2) - some portion of area may not be in county for a given element
2. highway mileage by type of highway in rural areas (street details not given on maps)
3. presence and amount of surface water suitable for boating
4. area in open land suitable for farming
5. area in towns, cities, and incorporated places
6. number of dwellings (some counties) in rural areas

To indicate typical detail given on a county highway map (scale is 1/2 inch = 1 mile or 1:126, 720), a section of the map for St. Louis County, Missouri is included as Figure 1. Several of the grid elements have been laid out on this map section to document their appearance, the larger ones being 5 km square and the smaller ones 2 km square. The computer program (a copy of which is in Appendix D) prints geographical coordinates to the nearest 0.01 second of angle, which represents the nearest 8×10^{-5} inch for longitude and the nearest 1×10^{-4} inch for latitude on the maps. It is obvious that the grids cannot be plotted with this kind of accuracy, and a reasonable estimate of accuracy is ±0.02 inches on the map or an actual error of ±65 m on the ground.

The distributions of several engine categories under investigation in this methodology development program are probably related more strongly to population than to any other single variable. Population data by grid element, however, are not available from any known source. It seems desirable to have a system for allocating population to grid elements; so this problem will be analyzed here before addressing specific methodologies for engine categories. Neglecting population density variations within incorporated places (incorporated places are outlined on county highway maps), grid element population can be estimated by

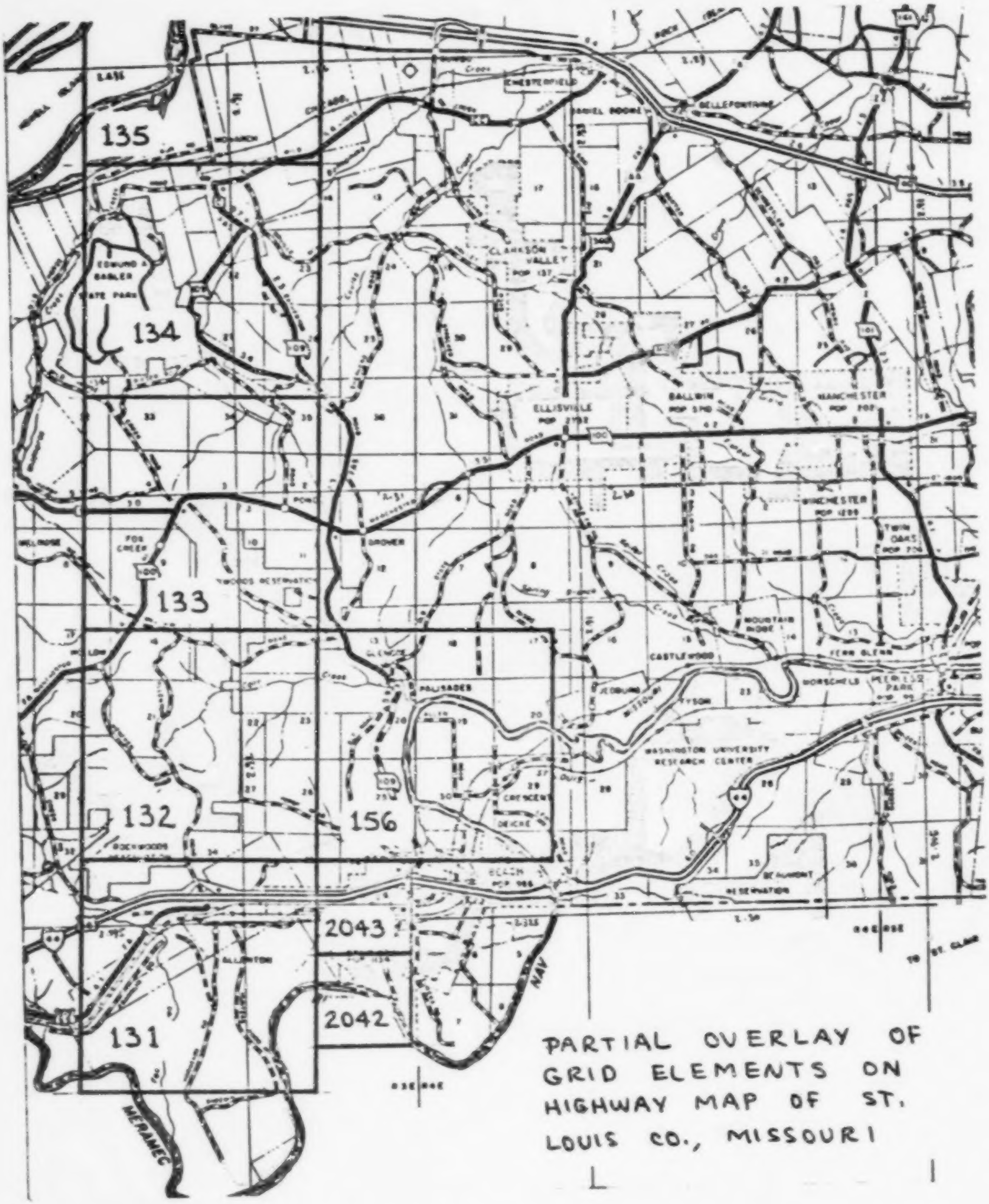
135
134
133
132
156
131
2043
2042
CHESTERFIELD
CLARKSON VALLEY
ELLISVILLE
BALLWIN
MANCHESTER
WINCHESTER
TWIN OAKS
EDMUND A. BABLER STATE PARK
FOX CREEK
GROVER
GLENCOE
PALISADES
CASTLEWOOD
CRESCENT
WASHINGTON UNIVERSITY RESEARCH CENTER
ALLENTON
MERAMEC
PARTIAL OVERLAY OF GRID ELEMENTS ON HIGHWAY MAP OF ST. LOUIS CO., MISSOURI

Figure 1. Sample layout of grid elements on a county highway map

$$\text{grid element population} = \left(\frac{\text{privately-owned grid land area}}{\text{area of incorporated place}}\right) \times (\text{population of incorporated place}).$$

Grid element area is given by definition, and both the other variables can be obtained from Appendix B, Table B-2 of the County and City Data Book(39) for places having a population of 2500 or more. Places having fewer than 2500 people are outlined on county highway maps, and their populations are given; so both variables can still be obtained (area to be measured by geometric sections or polar planimeter). For a serious effort directed at grid element estimates, larger-scale maps than the ones obtained for reference during this project should be available and are highly recommended for use.

Population estimates for grid elements not in incorporated areas are not as simple as those for incorporated areas. In this case, the best which can be done is to allocate (by area) the county's rural population to land remaining after all incorporated areas have been subtracted. This process takes the form

$$\text{grid element population} = \left(\frac{\text{privately-owned grid land area}}{\text{county unincorporated area}}\right) \times (\text{county farm population} + \text{county rural nonfarm population}),$$

where "county unincorporated area" can be determined by subtracting areas of incorporated places from total county area. An easier but somewhat less rigorous estimate could be made by assuming that "county unincorporated area" is equal to county area in farms(39), with small probable errors in most parts of the country.

Although not mentioned specifically thus far, grid elements which contain parts of two incorporated places, and/or two counties, and/or both incorporated and unincorporated places will have to be treated in separate parts. After the parts have been analyzed, the grid total population estimate can be summed.

A. OUTBOARDS

The major variable by which boating can be allocated to grids is availability of surface water of a suitable nature. The relationship proposed for outboard emission estimates is

$$\text{grid element emissions (kg/yr)} = (\text{county emissions, kg/yr}) \times \left(\frac{\text{grid surface water area}}{\text{county surface water area}}\right).$$

The equation should be satisfactory where all county surface water is suitable for boating, but the accepted total county figure(41) should probably be revised if some water geometrically OK for boating is heavily polluted, moving very swiftly, or otherwise unfit for use by small boats. The degree of care exercised on this point depends on the desired accuracy of the estimate and the amount of detailed data available for the area under study. Surface water areas for grid elements can be determined by measurement (e.g., by polar planimeter) using maps of the largest practically available scale. On a map such as the segment shown in Figure 1, minimum-size features used as input to tabular data(41) are represented by ponds 0.14 inch in diameter and rivers 0.062 inch wide. This reporting guideline does not necessarily reflect a typical minimum water area for outboard operation, but it would be an involved matter to form a new criterion since re-measurement of all the county's inland water area would be involved. In all cases, county surface water area from Reference 41 should be checked (at least roughly) against the county map, because many reservoirs have been built since 1960.

B. SNOWMOBILES

Emissions from snowmobiles will be allocated on an area basis, since urban and non-urban ownership and usage patterns have already been accounted for in the county methodology. The relationship which follows is

$$\text{grid element emissions (kg/yr)} = \left(\frac{\text{grid element land area}}{\text{county land area}}\right) \times \text{(county emissions, kg/yr)}.$$

This estimate could be modified by adding lakes which might be frozen during the snowmobile season to the area terms, but such a modification could hardly be justified by the accuracy of the overall estimate in most cases. In the same way, uniform subtractions of areas in which snowmobiles do not run can probably not be justified.

C. MOTORCYCLES

Although some other variables may be significant, motorcycles in service and their usage are probably related strongly to distribution of population within the county. It is proposed, therefore, that the grid element estimates for motorcycles be determined by the relationship

$$\text{grid element emissions (kg/yr)} = \text{(county emissions, kg/yr)} \times \left(\frac{\text{grid population estimate}}{\text{county population}}\right);$$

where the grid population estimate is made as described above.

D. LAWN AND GARDEN EQUIPMENT

Following the same general method used in allocating emissions from lawn and garden equipment to counties, it will still be attempted to apportion these emissions to grids according to location of one-unit housing structures. Using the technique developed earlier for estimating grid element population, the relationships which result are

$$\text{grid element emissions (kg/yr)} = \left(\frac{\text{grid one-unit structures}}{\text{county one-unit structures}}\right) \times \text{(county emissions, kg/yr)}$$

and

$$\text{grid one-unit structures} = \text{(grid population)} \left(\frac{\text{area one-unit structures}}{\text{area population}}\right).$$

The last term in the second equation is available for cities of 25,000 or more in tabular form(39). In all other privately-owned areas, the value of that term will be assumed as 0.230, which is the national average(39).

E. CONSTRUCTION AND INDUSTRIAL EQUIPMENT

It is doubtful that any of the intrinsic properties of grid elements correlate directly with construction equipment usage. While major construction projects such as highways, sewer systems, and large buildings are built to serve people's needs, they are often built on the periphery of the densely-populated areas. Industrial areas are also often located near, but not in, the most heavily-populated areas. These industrial areas can be pinpointed, however, by examining zoning maps for the area of interest if extreme accuracy is desired.

Having noted the shortcomings of the method, it is still necessary (due to lack of other data) to allocate construction and industrial engine emissions by population. The method derived earlier for grid population estimates can be used in the relationship

$$\text{grid element emissions (kg/yr)} = \left(\frac{\text{estimated grid element population}}{\text{county population}}\right) \times \text{(county emissions, kg/yr)}.$$

A more refined technique, using zoning laws, can be applied to industrial engine emissions in areas of industrial zoning. This technique results in the equation

$$\text{grid element emissions (kg/yr)} = \left(\frac{\text{grid element area in industrial/ commercial zones}}{\text{county area zoned industrial/ commercial}}\right) \times \text{(county emissions, kg/yr),}$$

and this second technique is considered highly preferable to the population-based method where the necessary information is available.

F. FARM EQUIPMENT

It will be assumed that emissions from farm equipment correlate well with area (acreage) in farms, leading to the relation

$$\text{grid element emissions (kg/yr)} = \left(\frac{\text{privately-owned unincorporated grid area}}{\text{county area in farms}}\right) \times \text{(county emissions, kg/yr).}$$

Depending on the desired level of accuracy, the term in the denominator could be checked against the county sum of privately-owned unincorporated area, which it is assumed to equal. If the two are not equal, then "county area in farms" could be replaced by "county privately-owned unincorporated area" to make the sum of the grid/county ratios equal 1.0.

VII. SUMMARY

All the phases of this study have been completed, but it should not be assumed that the results are a completely authoritative and correct analysis of emissions and fuel consumption on a county basis. Throughout the narrative, it has been stressed that achieving the project's objectives has often required usage of data which are really insufficient for the task. The results must be used only with full knowledge of their limitations, most of which were known even before the study began.

Most of the basic emissions data on which county methodologies (and hence grid methodologies) were derived are probably quite accurate; but even from the points at which modal data were combined to yield composite data or individual vehicle/engine data were combined to produce category data, errors have certainly occurred. In all cases, however, so many variables are missing that the errors cannot be estimated statistically. Proper use of the study's results, then, requires the knowledge that they are limited to estimates of an accuracy commensurate with the time and effort which went into the project. In other words, the estimates are reasonably good but in no way rigorous.

A number of good sources of emissions, population, and usage data were found; and these sources are essentially the composition of the List of References. A few References (e.g., 7-10, 39, 41, and perhaps others) are primarily sources of county data relatable to vehicle or engine population or usage, and a more complete list of these documents is found in Table 19. Secondary sources of county/small area data are listed in Appendix B, but they were not used much in preparation of this report.

The county and grid element methodologies themselves have been structured as much as possible to permit "plugging in" values with little or no prior computation involved. In some cases, values will have to be processed before use, such as those for percentages of state population in a given county. It is simply not practical here to convert all data to be used in the methodologies to compatible terms, especially since the methodologies may not be used for all areas at any foreseeable time.

Due to the length of equations and explanations used in the methodologies, it is not considered practical to reiterate them all in this section. It is in order, however, to give an assessment of the estimated relative accuracy of the methodologies. A rank-ordering from most accurate to least accurate is as follows:

1. farm equipment
2. motorcycles
3. construction equipment
4. lawn and garden, and outboards (tie)
5. industrial equipment and snowmobiles (tie)

This assessment is based first on availability of county population data, then on accuracy of emissions data, and finally on availability of usage information.

As shown in Table 32, total emissions from sources under study in this project exceed by considerable margins those estimated for off-highway internal combustion engine sources by the NEDS system. The basis for the NEDS estimates is not known at this time. To further compare emissions estimated by the methodologies developed herein to NEDS figures, Table 33 is presented to illustrate the impact of off-highway source emissions on totals for AQCR 070. This comparison shows estimated emissions of HC, CO, and NO_x from uncontrolled engines to be small but significant contributors to air pollution around St. Louis. It likewise shows that these engines do not contribute significantly to total particulate or SO_x emissions in that area.

Table 33. IMPACT OF OFF-HIGHWAY SOURCES ON EMISSIONS IN AQCR 070

Source categories	Emissions, 10^3 kg/yr				
	HC	CO	NO_x	Part.	SO_x
NEDS area sources	196,541	922,148	111,181	34,043	42,730
NEDS point sources	71,194	2,573,063	282,132	287,709	1,077,113
NEDS all sources	295,123	3,495,211	393,314	321,752	1,119,843
NEDS gasoline off-highway	4,050	22,200	1,290	59	36
NEDS diesel off-highway	337	2,050	3,370	118	246
NEDS all off-highway	4,390	24,200	4,660	177	282
Off-highway (this report)	12,800	101,000	19,400	1,620	1,430
- as % NEDS total	4.34	2.89	4.93	0.504	0.128

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APPENDIX A

TABULAR DATA ON POPULATION, USAGE, AND EMISSIONS OF SELECTED MOBILE SOURCE CATEGORIES

Table A-1. 1973 BOAT REGISTRATIONS AS COMPILED BY THE U. S. COAST GUARD(1)

State	Outboard boats	State	Outboard boats
Alabama	131,933	Nebraska	31,266
Alaska	11,642	Nevada	14,170
Arizona	41,706	New Hampshire	6,844
Arkansas	67,201	New Jersey	93,746
California	264,085	New Mexico	22,141
Colorado	29,027	New York	295,171
Connecticut	54,159	North Carolina	87,716
Delaware	17,027	North Dakota	12,085
Dist. of Columbia	2,349	Ohio	127,509
Florida	219,433	Oklahoma	125,686
Georgia	53,414	Oregon	85,337
Hawaii	8,185	Pennsylvania	119,872
Idaho	36,541	Rhode Island	10,483
Illinois	182,120	South Carolina	119,206
Indiana	91,264	South Dakota	18,049
Iowa	100,009	Tennessee	161,136
Kansas	61,100	Texas	385,196
Kentucky	82,586	Utah	19,264
Louisiana	102,868	Vermont	21,369
Maine	29,441	Virginia	96,407
Maryland	57,579	Washington	78,110
Massachusetts	103,823	West Virginia	11,971
Michigan	512,302	Wisconsin	331,980
Minnesota	306,165	Wyoming	7,362
Mississippi	37,545	Guam	437
Missouri	105,013	Puerto Rico	7,200
Montana	13,299	Virgin Islands	2,802
		Total including 48 states and D. C.	4,984,065

Table A-2. ESTIMATED STATE DISTRIBUTION OF OUTBOARD MOTORS, DECEMBER 31, 1973(2)

State	Motors	State	Motors
Alabama	150,000	Nebraska	38,000
Arizona	44,000	Nevada	16,000
Arkansas	121,000	New Hampshire	43,000
California	385,000	New Jersey	185,000
Colorado	38,000	New Mexico	19,000
Connecticut	92,000	New York	534,000
Delaware	23,000	North Carolina	134,000
Dist. of Columbia	26,000	North Dakota	24,000
Florida	527,000	Ohio	293,000
Georgia	152,000	Oklahoma	114,000
Idaho	43,000	Oregon	114,000
Illinois	312,000	Pennsylvania	195,000
Indiana	201,000	Rhode Island	28,000
Iowa	103,000	South Carolina	129,000
Kansas	71,000	South Dakota	20,000
Kentucky	99,000	Tennessee	167,000
Louisiana	292,000	Texas	470,000
Maine	86,000	Utah	35,000
Maryland	131,000	Vermont	23,000
Massachusetts	177,000	Virginia	120,000
Michigan	482,000	Washington	185,000
Minnesota	380,000	West Virginia	27,000
Mississippi	68,000	Wisconsin	370,000
Missouri	196,000	Wyoming	8,000
Montana	20,000		
		Total	7,510,000

Table A-3. U. S. SNOWMOBILE REGISTRATIONS AS OF MARCH 1, 1974[11]

State	Snowmobiles
Alaska	20,100
Arizona	1,000
California	15,000
Colorado	23,000
Connecticut	15,300
Idaho	32,000
Illinois	34,500
Iowa	26,000
Maine	75,260
Massachusetts	71,900
Michigan	400,000
Minnesota	290,400
Montana	30,000
Nebraska	400
Nevada	3,000
New Hampshire	49,000
New Jersey	12,000
New Mexico	2,100
New York	172,776
North Dakota	37,751
Ohio	12,500
Oregon	10,600
Pennsylvania	60,000
Rhode Island	1,050
South Dakota	25,077
Utah	13,500
Vermont	13,013
Washington	10,500
Wisconsin	233,569
Wyoming	12,000
Total U. S.	1,714,796

Table A-4. 1973 MOTORCYCLE REGISTRATIONS BY STATE[18]

State	Motorcycles	State	Motorcycles
Alabama	65,560	Montana	37,133
Alaska	15,143	Nebraska	45,000
Arizona	62,768	Nevada	15,434
Arkansas	34,036	New Hampshire	20,544
California	631,961	New Jersey	69,208
Colorado	81,871	New Mexico	30,799
Connecticut	51,440	New York	91,575
Delaware	6,050	North Carolina	95,435
Dist. of Columbia	4,045	North Dakota	18,738
Florida	142,478	Ohio	179,359
Georgia	90,454	Oklahoma	94,156
Hawaii	12,000	Oregon	100,203
Idaho	45,936	Pennsylvania	231,475
Illinois	177,487	Rhode Island	15,190
Indiana	99,000	South Carolina	33,232
Iowa	118,545	South Dakota	19,785
Kansas	99,399	Tennessee	74,000
Kentucky	49,112	Texas	257,400
Louisiana	40,000	Utah	51,375
Maine	20,713	Vermont	8,981
Maryland	44,000	Virginia	69,000
Massachusetts	67,000	Washington	91,184
Michigan	269,185	West Virginia	48,703
Minnesota	119,277	Wisconsin	77,080
Mississippi	130,000	Wyoming	14,893
Missouri	95,263		
		Total	4,362,605

Table A-5. MOTORCYCLE BREAKDOWNS BY SIZE FOR REGIONS OF THE UNITED STATES[19]

"Region" of the U.S.	Motorcycle size distribution Displacement, cc	 % of population	States included in "region"
New England	90 and less 91-190 191-290 291 and over Unclassified	9 20 9 59 3	Connecticut Maine Massachusetts New Hampshire Rhode Island Vermont
Middle Atlantic	90 and less 91-190 191-290 291 and over Unclassified	20 22 12 46 0	New Jersey New York Pennsylvania
East North Central	90 and less 91-190 191-290 291 and over Unclassified	23 22 11 42 2	Illinois Indiana Michigan Ohio Wisconsin
West North Central	90 and less 91-190 191-290 291 and over Unclassified	18 26 11 45 0	Iowa Kansas Minnesota Missouri Nebraska North Dakota South Dakota
South Atlantic	90 and less 91-190 191-290 291 and over Unclassified	22 25 10 40 3	Delaware Dist. of Columbia Florida Georgia Maryland North Carolina South Carolina Virginia West Virginia

table continued next page

Table A-5 (continued). MOTORCYCLE BREAKDOWNS BY SIZE FOR REGIONS OF THE UNITED STATES(19)

"Region" of the U.S.	Motorcycle size distribution		States included in "region"
	Displacement, cc	% of population	
East South Central	90 and less	24	Alabama
	91-190	27	Kentucky
	191-290	3	Mississippi
	291 and over	40	Tennessee
	Unclassified	6	
West South Central	90 and less	21	Arkansas
	91-190	33	Louisiana
	191-290	7	Oklahoma
	291 and over	36	Texas
	Unclassified	3	
Mountain	90 and less	28	Arizona
	91-190	32	Colorado
	191-290	10	Idaho
	291 and over	22	Montana
	Unclassified	8	Nevada
			New Mexico
			Utah
			Wyoming
Pacific	90 and less	20	Alaska
	91-190	27	California
	191-290	16	Hawaii
	291 and over	35	Oregon
	Unclassified	2	Washington

Table A-6. SALES, PRODUCTION, AND POPULATION ESTIMATES FOR LAWN AND GARDEN EQUIPMENT

Previous Population Estimate for Small Utility Engines (1968-All)(14)

Engine type	Average rated hp	Engines in service
Lawn and garden 4-stroke	3.43	36,200,000
Lawn and garden 2-stroke	3.43	2,500,000
Miscellaneous 4-stroke	3.86	5,550,000
	Total	44,250,000

Outdoor Equipment Sales and Population Estimates(30)

	Sales or population for sales year, millions						
Type of equipment	[a]1973	1972	1971	1970	1969	1968	1967
Walking mowers	5.45	5.2	4.7	4.7	4.7	4.56	4.9
Lawn tractors and riding mowers	0.74	0.68	0.88	0.95	1.0	0.93	0.25
Garden tractors	0.26	0.25	b	b	b	b	b
Total lawn and garden	6.45	6.13	5.58	5.65	5.7	5.49	5.15
Estimated total in use	--	43.	38.	37.	36.	--	--
Motor tillers	0.43	0.43	0.36	0.36	0.38	0.38	0.35
Snow throwers	0.33	0.32	0.26	0.24	0.26	0.26	0.18

[a] Prediction

[b] Included with lawn tractors and riding mowers.

Breakdown of 1966-1970 Small Engine Production by Application(31)

Application	Production (millions)	% of total
Riding mower	2.84	7.1
Walking mower	23.67	59.4
Garden tractor	1.19	3.0
Motor tiller	1.70	4.3
Snow thrower	1.18	3.0
Other lawn and garden	1.31	3.3
Total lawn and garden	31.89	80.0
Recreation	1.10	2.8
Industrial	2.65	6.6
Agriculture	0.97	2.4
Miscellaneous	3.27	8.2
Total	39.88	100.0

Table A-7. EMISSION FACTORS AND FUEL CONSUMPTION FOR CONSTRUCTION EQUIPMENT BY CATEGORY AND REFERENCE

Equipment category	Diesel or gasoline	Ref.	Brake specific emissions, g/hp hr						BSFC
			HC	CO	NO_x	Part.	RCHO	SO_x	g/hp hr
Tracklaying tractors	Diesel	38[a]	0.69	2.39	9.08	0.69	-	0.85	-
		34	0.685	2.39	9.08	0.692	0.17	0.851	193.
Tracklaying loaders	Diesel	38[a]	0.36	1.80	6.56	0.66	-	0.85	-
		34	0,362	1.80	6.56	0.655	0.10	0.853	194.
Motor graders	Diesel	38[a]	1.68	4.08	9.03	1.51	-	0.92	-
		34	0.532	2.15	10.6	0.613	0.12	0.874	199.
	Gasoline	38[a]	7.18[b]	218.	5.24	0.37	-	0.22	-
		34	8.62[c]	187.	4.92	0.320	0.30	0.26	295.
	Both	34	0.936	11.4	10.3	0.598	0.13	0.844	-
Scrapers	Diesel	38[a]	1.22	2.84	12.1	0.79	-	0.90	-
		34	1.22	2.84	12.1	0.789	0.28	0.901	205.
Off-highway	Diesel	38[a]	0.85	2.62	14.9	0.50	-	0.89	-
		34	0.853	2.62	14.9	0.502	0.22	0.887	201.
Wheel loaders	Diesel	38[a]	1.70	3.34	9.39	1.28	-	0.87	-
		34	0.948	2.63	11.2	0.810	0.20	0.857	195.
	Gasoline	38[a]	6.86[b]	143.	6.62	0.37	-	0.23	-
		34	7.35[c]	163.	5.41	0.312	0.22	0.244	276.
	Both	34	1.97	28.3	10.3	0.730	0.20	0.759	-
Wheel tractors	Diesel	38[a]	1.70	3.34	9.39	1.28	-	0.87	-
		34	1.39	4.40	9.34	1.27	0.28	0.851	193.
	Gasoline	38[a]	6.86[b]	143.	6.62	0.35	-	0.23	-
		34	7.41[c]	142.	6.37	0.360	0.26	0.230	269.
	Both	34	1.99	18.1	9.05	1.18	0.28	0.789	-
Rollers	Diesel	38[a]	1.68	4.08	9.03	1.51	-	0.92	-
		34	0.777	3.64	15.8	0.777	0.20	1.00	228.
	Gasoline	38[a]	7.18[b]	218.	5.24	0.37	-	0.23	-
		34	12.0[c]	202.	5.47	0.394	0.25	0.279	325.
	Both	34	6.71	193.	8.57	0.506	0.24	0.495	-

table continued next page

Table A-7 (continued). EMISSION FACTORS AND FUEL CONSUMPTION FOR CONSTRUCTION EQUIPMENT BY CATEGORY AND REFERENCE

Equipment category	Diesel or gasoline	Ref.	Brake specific emissions, g/hp hr						BSFC g/hp hr
			HC	CO	NO_x	Part.	RCHO	SO_x	
Wheel dozers	Diesel	38[a]	0.58	1.83	12.5	0.41	-	0.87	-
		34	0.576	1.83	12.5	0.411	0.16	0.867	197.
General purpose	Diesel	38[a]	1.68	4.08	9.03	1.51	-	0.92	-
		34	1.03	2.82	14.8	0.907	0.20	0.933	212.
	Gasoline	38[a]	7.18[b]	218.	5.24	0.37	-	0.23	-
		34	8.3[c]	198.	4.79	0.300	0.23	0.273	308.
	Both	34	1.85	32.1	13.3	0.816	0.21	0.834	-
All equip't.	Both	34	1.45	14.9	9.61	0.731	0.20	0.752	-
Earth-movers only	Diesel	35[d]	0.958	2.84	6.53	-	-	-	-
		36[e]	0.630	3.19	8.94	0.29	-	1.53	-
		34	1.04	2.90	9.62	0.633		0.769	-

[a] All Reference 38 values based on Reference 34.

[b] 25 percent allowance included for evaporative and crankcase emissions.

[c] Allowance included for evaporative and crankcase emissions (variable).

[d] Estimate for 1969 made in 1970.

[e] Estimate for 1969 made in 1972.

APPENDIX B

LIST OF COUNTY DATA SOURCES

PRIMARY SOURCES

1. County and City Data Book, A Statistical Abstract Supplement. U. S. Department of Commerce. 1972.

2. 1969 Census of Agriculture, Volume I - Area Reports. U. S. Department of Commerce, Bureau of the Census.

3. Area Measurement Reports. U. S. Department of Commerce/ Bureau of the Census. Publication GE-20, No. 1. May 1970.

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5. Statistical Abstract of Ohio - 1969. Economic Research Division Development Department.

6. South Carolina Statistical Abstract - 1973. South Carolina Budget and Control Board, South Carolina Division of Research and Statistical Services. July 1973.

7. Wisconsin Statistical Abstract - Third Edition. Department of Administration, State Bureau of Planning and Budget, Information Systems Unit. June 1974.

8. Motor Vehicle Units Registered for the Year 1973. State of Illinois. Accounting Revenue Division.

9. 1973 County Audit Report. Missouri Department of Motor Vehicles.

SECONDARY SOURCES

10. Economic Abstract of Alabama 1972. Center for Business and Economic Research, Graduate School of Business, The University of Alabama, University, Alabama, December 1972.

11. Arizona Statistical Review. Phoenix, Arizona, Economic Research Department, September 1973.

12. The Arkansas Almanac 1972. Little Rock, Arkansas, Arkansas Alamanca, Incorporated.

13. California Statistical Abstract 1973. Sacramento, California, 1973.

14. Delaware Statistical Abstract 1974. Social and Economic Analysis Section, Delaware, State Planning Office, Dover, Delaware.

15. Florida Statistical Abstract 1973. Gainsville, Florida, University of Florida Press, August 1973.

16. Norman Nybroten. Idaho/1971 Statistical Abstract, Moscow, Idaho, University of Idaho, August 1971.

17. 1972 Edition Illinois State and Regional Economic Data Book. State of Illinois Department of Business and Economic Development.

18. 1972 Statistical Profile of Iowa. Des Moines, Iowa, The Iowa Development Commission.

19. Kansas Statistical Abstract 1973. Institute for Social and Environmental Studies, The University of Kansas, Lawrence, Kansas.

20. Statistical Abstract of Louisiana. Division of Business and Economic Research, College of Business Administration, Louisiana State University in New Orleans. Fourth Edition 1971.

21. 1973 Maryland Statistical Abstract. Department of Economic and Community Development, State of Maryland, Annapolis, Maryland.

22. Michigan Statistical Abstract, Tenth Edition 1974. East Lansing, Michigan, Michigan State University.

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25. Data for Missouri Counties. Columbia, Missouri, University of Missouri.

26. Montana Data Book. Helena, Montana, Department of Planning and Economic Development, State of Montana, 1970.

27. Nebraska Statistical Handbook, 1974-1975. Lincoln, Nebraska, The Nebraska Department of Economic Development.

28. New Mexico Statistical Abstract 1972. Albuquerque, New Mexico, The University of New Mexico.

29. North Carolina State Government Statistical Abstract, Second Edition 1973. Statistical Services Section, Office of State Budget, Department of Administration.

30. Statistical Abstract of Oklahoma 1972. Norman, Oklahoma, Bureau for Business and Economic Research, University of Oklahoma, May 1973.

31. Pennsylvania Abstract 1973. Harrisburg, Pennsylvania, Department of Commerce.

32. Tennessee Statistical Abstract 1971. Knoxville, Tennessee, Center for Business and Economic Reasearch, The University of Tennessee.

33. Texas Almanac and State Industrial Guide 1972-1973. A. H. Belo Corporation.

34. Statistical Abstract of Utah 1973. Bureau of Economic and Business Research, Center for Economic and Community Development, University of Utah.

35. Vermont Facts and Figures 1973. Montpelier, Vermont, Vermont Department of Budget and Management, March 1973.

36. Statistical Abstract of Virginia 1966, Vol. I and 1970, Vol. II. Charlottsville, Virginia, University of Virginia.

37. The Research Council's Handbook, Fourth Edition. Olympia, Washinton, Washington State Research Council.

38. The 1973 Statistical Handbook. Charleston, West Virginia, West Virginia Research League, Inc.

39. Wyoming Data Book 1972. Laramie, Wyoming, Division of Business and Economic Research, University of Wyoming.

APPENDIX C

DOCUMENTATION OF COUNTY METHODOLOGY DEVELOPMENT

DOCUMENTATION OF COUNTY METHODOLOGY DEVELOPMENT

The purpose of this Appendix is to present procedures utilized in arriving at two of the county methodologies described in Section IV, including several methods which proved unsuccessful. The categories for which this presentation will be made are outboard motors and snowmobiles. Methodologies for the other categories were developed in a more straightforward way because either (1) ample information was available on which to base a logical method or (2) insufficient information was available to check on the method developed. In the first case, the methodologies will yield emissions data having good accuracy. In the second case, the accuracy of calculated values simply cannot be assessed; so they must be accepted as gross estimates. The categories for which good data are available are motorcycles and farm equipment. Those for which few data are available are lawn and garden equipment, construction equipment, and farm equipment.

1. Outboard Motors

A number of general regression analyses were attempted; and to show the results concisely, the following terms are defined:

f1 = percent of state boat registrations in county
f2 = percent of state boat usage in county
f3 = percent of state population in county
f5 = percent of state inland water area in county.

Data were obtained on f1, f3, and f5 for New York(7), Ohio(8), South Carolina(9), and Wisconsin(10). Data on f2 were obtained only for New York. Regressions were calculated for all the data together, and also for individual states, urban and rural areas, and coastal and inland areas. The results of these regression analyses are shown in Table C-1, and none of the general ones is very promising.

Another approach tried was to characterize the outboard population in terms of generalities and then to fit a mathematical model to these generalities once complete. The observations and calculated data were the following:

(a) Boat registrations are basically proportional to population in each state.
(b) Except for inland counties having no surface water usable for boating ("dry" counties), boats used correlate strongly with boat registrations (r^2 over 0.9). To be recorded, ponds must have areas of 40 acres (0.16 km^2) or more and streams must be at least 1/8 mile (0.20 km) wide.

Table C-1. REGRESSION ANALYSES ATTEMPTED ON OUTBOARD MOTOR DATA

Dependent variable	Independent variable(s)	Data utilized	Coefficient(s)			
			a	b	c	r^2
f2	f1	All NY	0.0431	0.905		0.892
f1	f3	All coastal	1.103	0.672		0.694
f1	f3	All inland	0.255	0.885		0.809
f1	f3	NY coastal	0.616	1.195		0.686
f1	f3	Ohio coastal	0.781	0.591		0.958
f1	f3	SC coastal	0.503	1.075		0.985
f1	f3	Wisc. coastal	0.545	0.532		0.991
f1	f3	NY inland	0.150	1.42		0.752
f1	f3	Ohio inland	0.172	0.880		0.836
f1	f3	SC inland	0.0874	0.910		0.813
f1	f3	Wisc. inland	0.340	0.873		0.766
f1	f3, f5	All NY	0.0627	1.257	0.146	0.795
f1	f3	All urban	3.97	0.420		0.372
f1	f3	All non-urban	0.222	0.927		0.806

(c) As an average, 9 percent more boats are used in coastal counties than are registered in those counties(7). This generalization includes counties bordering the great lakes as well as the oceans.

(d) Congested urban areas generally show fewer outboards registered than would be projected solely on a population basis.

The following terms were also defined:

ρ = county population density (inhabitants/mi^2), $\rho \geq 1000$ is criterion for urban county;

', '', ''' as superscripts indicate values after first, second, and third corrections (coastal-inland correction, dry-wet correction, and urban—non-urban correction, respectively);

c, i, d, w, u, and n as second subscripts mean "coastal", "inland", "dry", "wet", "urban", and "non-urban", respectively.

The estimation procedure was as follows:

(a) Assume f2 = f3 (f3, f5, and ρ, and an indicator of coastal or inland status should be tabulated by county for the state)

(b) Make the "coastal-inland" correction by calculating:

$f2'c = 1.09f2c$; $f2'i = f2i\left(1 - 0.09\dfrac{\sum f2c}{\sum f2i}\right)$; and tabulating by county.

(c) Make the "dry-wet" correction by calculating:

$f2''d = 0$; $f2''w = f2'w\left(1 + \dfrac{\sum f2'd}{\sum f2'w}\right)$; and tabulating by county.

(d) Make the "urban-rural" correction by calculating:

$f2'''u = \left(\dfrac{f2''u}{0.026\,\ell^{0.53}}\right)$; $f2''n = f2''n\left(\dfrac{\sum f2'' - \sum f2'''u}{\sum f2'' - \sum f2'''u}\right)$; and tabulating by county.

The values $f2'''$ were the final results for all the counties on a percentage basis and could be multiplied by the state boat population to yield the actual number of boats used in each county. While the method guarantees that the sum of the $f2'''$ equals 100 percent, the individual f''' did not agree very well with the individual f2 for New York ($r^2 = 0.35$).

2. Snowmobiles

The only county snowmobile registration data located were for New York[(7)], and a number of approaches were attempted before a usable relationship was found. The following terms are defined for convenience:

g1 = percent of state snowmobile registrations in county
g2 = percent of state snowmobile usage in county
g3 = percent of state population in county
g4 = snowfall, in/yr
g5 = development index = (number of snowmobile developments in county)$^{0.5}$.

The regression analyses attempted are described in Table C-2, verifying that snowmobile usage correlates well with registration. Table C-2 also shows that separating urban and rural areas enhances the accuracy of the estimate for rural areas and that the "development index" is only a marginal contributor to variability in usage. The expression second from the bottom of Table C-2 was the one modified for use in the methodology, along with an empirical correction to reflect low registrations and usage in congested urban areas. The modification consisted of normalizing the snowfall term to a percentage of snowfall at the state's geographical center, making the coefficient c take on the new value 0.0321.

Table C-2. REGRESSION ANALYSES ATTEMPTED ON NEW YORK SNOWMOBILE DATA

Dependent variable	Independent variable(s)	Data utilized	Coefficient(s)					r^2
			a	b	c	d	e	
g2	g1	All	0.0392	0.977				0.994
g2	g1, g5, g3, g4	All	-2.224	-0.00294	0.234	0.272	0.0478	0.425
g2	g1, g5, g3, g4	Non-urban	-2.418	-0.00175	0.143	1.576	0.0433	0.665
g2	g1, g3, g5, g4	Urban	0.119	0.981	-0.00272	0.0945	-0.00660	0.999
g2	g3	All	1.702	-0.0092				0.00016
g2	g4	All	-1.020	0.0400				0.317
g2	$(g5)^2$	All	1.306	0.111				0.0633
g2	g3, g4	All	-2.125	0.250	0.0521			0.408
g2	g3, g5, g4	All	-2.229	0.273	0.236	0.0476		0.424
g2	g3, g4	Non-urban	-2.345	1.560	0.0458			0.657
g2	g3, g4, g5	Non-urban	-2.424	1.579	0.0432	0.145		0.665

APPENDIX D

UTM TO GEOGRAPHIC COORDINATE CONVERSION PROGRAM

```
                   PROGRAM UTMGEO(INPUT,OUTPUT)
000003             DIMENSION YNORTH(4 ),XEAST(4),ILD(4),ILM(4),SLA(4)
000003             DIMENSION                        IGD(4),IGM(4),SNG(4)
            C      (DEGREES)   PROGRAM TRANSFORMS  UTM  TO GEOGRAPHIC
            C                  COORDINATES       (TBH-16-JAN-73)
000003             SCALE = .9996
000004             ESQ = .006768658
000006             SECRD = 4.848136811E-06
000007             SEPQ = .0408887094
000011             FE = 500000.
000012             EPSQ = ESQ/(1.-ESQ)
000015             IDIR = 0
000016             IZONE=15
000017             IPAGE=1
000020             LCT=58
000021          32 READ 101,ID,XEAST,YNORTH
000033             IF(ID   .EQ.0) GO TO 99
000034             XZONE = IZONE
000036             DO 200 I=1,4
000037             YY=YNORTH(I)
000040             XX=XEAST(I)
000042             CM = (6. * XZONE - 183.) * 3600.
000045             PPRD = (YY * .1570499810 * 10.0E-7) / SCALE
000050             SNLT = SIN(PPRD)
000052             CSLT = COS(PPRD)
000054             CSSQ = CSLT * CSLT
000055             PHRD = ((CSSQ*.24682+30.02335)*CSSQ+5078.64977)*(SNLT*CSLT)
                  1*10.E-7 + PPRD
000067             PHIS = PHRD/SECRD
000070             Q = (XX-FE)*10.E-7
000073             IF(Q.NE.0) GO TO 720
000075             DLAM = 0.
000075             XLAT = PHIS
000077             GO TO 740
000100         720 CONTINUE
000100             SNLAT = SIN(PHRD)
000102             CSLAT = COS(PHRD)
000104             SNSQ = SNLAT * SNLAT
000106             CCSQ = CSLAT * CSLAT
000107             TNLAT = SNLAT/CSLAT
000110             TNSQ = TNLAT * TNLAT
000111             ENU = 6378206.4 / SQRT(1.-ESQ*SNSQ)
000117             ENSNS = ENU * SECRD
000121             EPCS = EPSQ * CCSQ
000123             EPCSQ = 1. + EPCS
000124             QSQ = Q*Q
000126             QCU = QSQ * Q
000127             QFR = QCU * Q
000130             QFV = QFR * Q
000131             QSX = QFV * Q
000132             SCLAT = 1./CSLAT
000133             ENSNS = ENU**4 * ENSNS
000136             SVN = (((TNLAT/(2.*ENU*ENSNS))*EPCSQ)/(SCALE*SCALE))*10.E11
000145             EG=5.+3.*TNSQ+SEPQ*(CCSQ-SNSQ)-(3.*EPSQ**2*CCSQ)*(CCSQ+3.
                  1*SNSQ)
000162             EGM = TNLAT/(24.*ENU**3*ENSNS)
000166             EGMT = (EGM*EG/SCALE**4)*10.E+23
```

```
000172         D61=61.+(45.*TNSQ)*(2.+TNSQ-EPSQ*SNSQ)+EPSQ*(107.*CCSQ
              1-162.*SNSQ)
000206         D62=TNLAT/(720.*ENU**5*ENSNS)
000213         D6 = (QSX*D62*D61/SCALE**6)*10E+35
000220         ANINE = (SCLAT/ENSNS)/SCALE*10.E5
000223         TEN = (SCLAT/(6.*ENU**2*ENSNS))*(1.+2.*TNSQ+EPCS)
              1/SCALE**3*10.E17
000236         ES = QFV*(SCLAT/(120.*ENSNS))*(5.+(4.*TNSQ)*(7.+6.*TNSQ)
              1+(2.*EPSQ)*(3.*CCSQ+4.*SNSQ))/SCALE**5*10.E24
000264         XLAT = PHIS-SVN*QSQ + EGHT*QFR - D6
000272         DLAM = ANINE*Q - TEN*QCU +ES
000300     740 CONTINUE
000300         XLONG = CM + DLAM
000302         YLONG = -XLONG/3600.
000304         YLAT = XLAT/3600.
000306         ID1 = YLAT
000310         REM = (YLAT-ID1) * 3600.
000313         IM1 = REM/60.
000315         S1 = REM - (IM1*60.)
000320         ID2 = YLONG
000322         REM = (YLONG - ID2) * 3600.
000325         IM2 = REM/60.
000327         S2 = REM-(IM2*60.)
000332         ILD(I)=ID1
000335         ILM(I)=IM1
000336         SLA(I)=S1
000340         IGD(I)=ID2
000341         IGM(I)=IM2
000343         SNG(I)=S2
000344     200 CONTINUE
000346         IF(LCT .LT. 58) GO TO 40
000350         PRINT 104,IPAGE
000356     104 FORMAT(*1*,15X,*ST LOUIS AQCR GRID SQUARE COORDINATES*/* PAGE*,I3/
             1       *   ID          1               2               3              4*
             2   /10X,      *DEG MIN SEC    DEG MIN SEC    DEG MIN SEC    DEG MIN SE
             3C*)
000356         LCT=4
000357         IPAGE =IPAGE+1
000361      40 PRINT 102,ID,(ILD(I),ILM(I),SLA(I),I=1,4),
             1              (IGD(I),IGM(I),SNG(I),I=1,4)
000413         LCT=LCT+3
000415     101 FORMAT(I4,1X,-3P8F5.1)
000415     102 FORMAT(*0*,I4,*  LAT*,4(I4,I3,F6.2)/5X,* LONG*,4(I4,I3,F6.2))
000415         GO TO 32
000415     44  STOP
000417         END
```

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Methodology for Estimating Emissions from Off-Highway Mobile Sources for the RAPS		5. REPORT DATE 10-30-74
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Charles T. Hare		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Southwest Research Institute 8500 Culebra Road San Antonio, Texas 78284		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-02-1397
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Office of Air Quality Planning and Standards Research Triangle Park, North Carolina 27711		13. TYPE OF REPORT AND PERIOD COVERED Final Report 3/74-9/74
		14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

Emissions, population, and usage data existing in the technical literature have been collected and organized for the following unregulated sources: outboard motors, snowmobiles, motorcycles, lawn and garden equipment, construction equipment, industrial equipment, and farm equipment.

Methodologies for estimating emissions and fuel consumption on a county basis have been developed for the sources noted above. They have been demonstrated for counties in the St. Louis Metropolitan Air Quality Control Region (AQCR 070), and their strengths and weaknesses have been discussed. Methods have also been developed to apportion county emissions estimates to grid elements, but they have not been demonstrated. The exhaust constituents assessed include hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), particulate, aldehydes (RCHO), and oxides of sulfur (SO_x). For outboard motors, neither particulate nor aldehyde data were available; but carbon dioxide (CO_2) emissions were included.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Gro
Mobile Source Emissions Apportion Emissions		

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